The Relationship between Training Load and Perceived Sleep Quality and Quantity in Professional Rugby Sevens Players during an International Competitive Season

by

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Abstract

Sleep is an essential component in the performance of athletes. Exercise performed during the day might influence subsequent sleep and disrupt the quality and quantity (duration) thereof. How an athlete perceived the quality and quantity of sleep is important in monitoring their well-being. By knowing the effects of exercise on subsequent sleep as well as how sleep is affected during a competitive season, should assist coaches in the planning and scheduling of training sessions to allow adequate recovery for athletes. Athletes should also be educated on the value of good quality and quantity of sleep to enhance their performance.

The primary aim of this study was to determine if there is a relationship between variation in daily training load (dTL) and the subsequent night's perceived sleep quality (pSQ) and perceived sleep quantity as perceived sleep duration (pSD) of Rugby Sevens players. The secondary aim of this study was to determine if there is a relationship between pSQ and pSD in Rugby Sevens players as it was hypothesised by the researcher that there is a relationship between better sleep quality and longer sleep duration perceived by players. The third aim of this study was to determine if there was a change in training load during the 31-week season while the fourth aims were to determine if there was a change for pSQ and pSD for the same 31-week period.

During an international, 16 elite professional Rugby Sevens players from the South African National Rugby Sevens squad were observed for 31 weeks during a competitive season. Training load consists of two components: intensity, measured as the rate of perceived exertion (RPE) and the duration of the exercise sessions which was termed session training load (sTL) for the purpose of this study. For multiple training sessions or matches on a day, all sTL for the day were summed in order to provide the daily training load (dTL). This was measured for all training sessions, captain's runs and matches. Each player's dTL was correlated with pSQ and pSD for the subsequent night's sleep. The duration of training sessions or matches were also summed to provide the total training or match time for the day called the daily duration (dD). The highest intensity the player was exposed to for any of the exercise sessions on the day was termed the maximum RPE (mRPE) by using the highest RPE score provided for any of the sessions, should there have been more than one training session on a day or more than one match. For training sessions, captain's runs and matches mRPE and the dD were also correlated with the subsequent night's pSQ and pSD. Self-reported perceived sleep scores have been shown to be reliable in a team set-up.

After training sessions pSD were negatively impacted by the daily duration (DD) ($r = -0.16$) ($p < 0.01$), the intensity (mRPE) (-0.12) ($p < 0.01$) and the daily training load (dTL) (-0.17) ($p < 0.01$) of the training session. After matches pSQ was negatively impacted by the DD ($r = -0.4$) ($p < 0.01$) and dTL (-0.37) ($p < 0.01$) of the playing time in the matches. Neither pSQ nor pSD was significantly affected after captain's runs ($p > 0.05$). Furthermore, it seems that sleep quality and duration are coupled as A moderate positive correlation ($r = 0.32$, $p < 0.01$) was found between pSQ and pSD during the season. There was a significant difference in pSQ for each additional hour of pSD from more than five hours of sleep to more than eight hours of sleep ($p > 0.05$). These findings indicated that there might be a relationship between sleep duration and training load, intensity and the duration of training sessions after training sessions. Sleep quality might have a relationship with the training load and duration of playing time in matches. Also, sleep quality and sleep duration seem to have a positive relationship with each other. Lastly, no significant changes ($p > 0.05$) could be found between the start of the season and the end of the season for training load, pSQ and pSD.

Notwithstanding the results of this study that showed exercise might have an impact on subsequent sleep quality and quantity, other circumstances could also contribute to the findings. Body soreness, early morning training session and circadian desynchronization, for instance, are possible confounding variables which may hinder sleep quality and quantity of elite athletes. Acquiring a better understanding of how exercise and sleep influence each other can assist in planning to optimise performance. In the current study, only the effects of exercise on sleep were assessed. It might be relevant to examine the effects of the previous night's sleep on subsequent training in future studies. In conclusion, findings from this study indicate the need for elite athletes to increase sleep duration in order to enhance sleep quality which is closely coupled with performance benefits.

Keywords: Sleep, Quality, Quantity, Rugby Sevens, Training load, RPE.

Opsomming

Slaap is ’n noodsaaklike komponent wat ’n invloed het op atlete se prestasie. Oefening wat deur die dag gedoen word, kan die daaropvolgende nag se slaap beïnvloed en die slaapkwaliteit en slaapkwantiteit (duur) daarvan versteur. Atlete se ervaring ten opsigte van slaapkwaliteit en -kwantiteit is belangrik tydens die monitering van hul welstand. Begrip rakende die impak van daaglikse oefening op slaap sowel as hoe slaap geaffekteer word gedurende ’n kompetisieseisoen, kan afrigters help met die beplanning en skedulering van oefensessies om voorsiening te maak dat die atleet voldoende herstel. Sportlui kan ook baat vind by inligting oor die waarde van goeie slaapkwaliteit en -kwantiteit om prestasie te bevorder.

Die primêre doel van hierdie studie was om te bepaal of daar ’n verwantskap is tussen variasie in daaglikse oefenlading (dTL) en die daaropvolgende nag se waargenome-slaapkwaliteit (pSQ) en -slaapkwantiteit as waargenome slaapduur (pSD) van rugbysewesspelers. . Die tweede doel van die studie was om te bepaal of daar ’n verwantskap tussen pSQ en pSD by rugbysewesspelers. Dit was die navorser se hipotese dat daar ‘n verwantskap is tussen beter slaapkwaliteit en langer slaapduur soos waargeneem deur spelers.

Gedurende ’n internasionale toernooi, 16 elite professionele rugbysewesspelers van die Suid-Afrikaanse Rugbysewesgroep is waargeneem vir 31 weke in ‘n seisoen waar daar gekompeteer is. Al die spelers wat deel was van die studie se ouderdom

het gewissel tussen 19 en 29 jaar. Oefenlading bestaan uit twee komponente, naamlik, intensiteit, gemeet as die waargenome oefenlading (RPE) en die daaglikse lengte van oefensessies. Die produk hiervan was sessie-oefenlading (sTL) genoem. Vir meer as een oefensessie of wedstryd per dag was sTL by mekaar getel vir die dag om die daaglikse oefenlading (dTL) te gee. Daaglikse oefenlading (dTL) was tydens al die oefensessies, kapteinsoefeninge en wedstryde gemeet. Dit is dan gekorreleer met pSQ en pSD tydens die daaropvolgende nag. Die lengte van oefensessies of wedtryde vir ‘n dag is ook saam getel om die daaglikse lengte van ‘n sessie te gee. Dit was daaglikse durasie genoem (DD). Vir meer as een oefensessie of wedstryd op ‘n dag was die sessie met die hoogste RPE waaraan ‘n speler blootgestel was die maksimum RPE telling (mRPE) vir die dag genoem. mRPE and DD was ook gekorreleer met pSQ en pSD soos ervaar tydens die daaropvolgende nag se slaap na oefensessies, wedstryde en kapteinsoefeninge. Elke aand se pSD is gemeet in minute en pSQ is gemeet op ’n skaal van 1 tot 10 in arbitrêre eenhede waar 1 die swakste ervaring en 10 die beste ervaring van slaapkwaliteit was. Self-gerapporteerde waargenome-slaaptellings binne die opset van ’n sportspan het getoon dat dit betroubaar is.

Resultate het getoon dat pSD na oefensessies negatief beïnvloed is deur die lengte van die oefensessie (DD) ($r = -0.16$) ($p < 0.01$), die intensiteit (mRPE) (-0.12) ($p < 0.01$) en die daaglikse oefenlading (dTL) (-0.17) ($p < 0.01$). Na wedstryde is pSQ negatief beïnvloed deur die lengte van wedstryde (DD) ($r = -0.4$) ($p < 0.01$) en die oefenlading (dTL) van wedstryde (-0.37) ($p < 0.01$). Nòg pSQ nòg pSD is beïnvloed na ’n kapteinsoefening. Verder is daar ’n redelike positiewe korrelasie tussen pSQ en pSD gedurende die seisoen gevind. Daar was 'n beduidende toename in pSQ vir elke bykomende uur van pSD. Hierdie bevindinge wys daarop dat slaapkwantiteit meer geneig was om na oefensessie beïnvloed te word deur oefenlading, intensiteit en die lengte van oefensessies. Slaapkwaliteit was weer meer geneig om beïnvloed te word deur wedstryde se oefenlading en intesiteit. Slaapkwaliteit en -kwanteit het 'n positiewe verwantskap met mekaar getoon. Laastens kon daar geen beduidende verskille gekry word tussen die beign en einde van 'n seisoen vir oefenlading, pSQ en pSD nie.

Nieteenstaande die resultate in hierdie studie wat toon dat oefening ’n impak het op slaapkwaliteit en -kwantiteit, mag daar ook bykomende faktore wees wat kan bydra tot die uitkoms van die studie. Lyfseer, vroeë-oggendoefensessies en desinkronisering van die liggaamlike sirkadiese ritme is voorbeelde van bydraende faktore wat spelers se slaapkwaliteit en -kwantiteit kan versteur. Om ’n beter begrip te hê van die invloed wat oefening en slaap op mekaar het, kan afrigters bemagtig om oefensessies en slaap so uit te werk dat spelers optimaal kan presteer. In die huidige studie is net die effek van oefening op slaap ondersoek, maar die impak van die vorige nag se slaap op oefen en prestasie mag nuttig wees vir toekomstigge studies. Verder beklemtoon die bevindings in hierdie studie die noodsaaklikheid van verlengde slaaptyd vir topspelers om slaapkwaliteit te verhoog wat kan bydra tot beter prestasie.

Sleutelwoorde: Slaap, kwaliteit, kwantiteit, rugbysewes, oefenlading, RPE.

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List of Abbreviations and Acronyms

#		Number
AAS	:	Ascending arousal system
ACTH	:	Adrenocorticotrophin hormone
ANOVA	:	Analysis of Variance
AU	:	Arbitrary Units
BDNF	:	Brain derived neurotrophic factor
cm	:	Centimeter
DD	:	Daily Duration
dTL	:	Daily Training Load
EEG	:	Electroencephalogram
EMG	:	Electromyography
GH	:	Growth Hormone
h	:	Hour
HR	:	Heart Rate
Hrpeak	:	Maximum Heart Rate
Hrreserve	:	Heart Rate Reserve
Kg	:	Kilogram
MEQ	:	Morning Evening Questionnaire
min	:	Minutes
mRPE	:	Daily Maximum RPE score
n	:	Sample Size
NREM	:	Non-rapid eye movement
p_val	:	Probability value
pSD	:	Perceived Sleep Duration
PSG	:	Polysomnography
pSQ	:	Perceived Sleep Quality
PSQI	:	Pittsburgh Sleep Quality Index
r	:	Correlation coefficient
R2	:	Correlation coefficient squared
REM	:	Rapid eye movement
rmcorr	:	Repeated measure correlation
RPE	:	Rate of Perceived Exertion
SCN	:	Suprachiasmatic nuclei
SD	:	Standard Deviation
sRPE	:	Session Rate of Perceived Exertion
sRPE	:	Session RPE
sTL	:	Session Training Load
TL	:	Training Load
VLPO	:	Ventrolateral preoptic nucleus system
VO2	:	Oxygen Consumption
VO2max	:	Maximal Aerobic Capacity
VO2peak	:	Peak Aerobic Capacity

Glossary

Sleep duration: Even though *sleep quantity* is the variable that is reported on and is used in the title, *sleep duration* is used in the text for easier reading and to avoid confusion between *quality* and *quantity* during the repetitive use of the terms.

Training load: For the purpose of this thesis *workload* and *training load* are referring to the same concept. To avoid confusion the term training load is used to report on the findings of the current study for training sessions, captain's runs and matches. Training also includes gym session and skills training sessions.

sRPE: Refers to the RPE score for a single training session or match.

sTL: Is the product of sRPE multiplied by the sDuration for each session on a day.

dTL: Refers to the summation of sTL for a day should there be multiple training session or matches on a day. If there was only one training session or one matches for the day the sTL is the dTL for that day.

mRPE: Refers to the maximum RPE score for a day if there were multiple sessions on a day. This was only used to determine the maximum intensity for a day. If there were only one training session on a day or only one match was played, that days sRPE score is the mRPE score as well.

CHAPTER ONE

INTRODUCTION

1.1 Background

Rugby Sevens is a popular form of Rugby Union, especially after its inclusion in the 2016 Summer Olympic Games (Williams, West, Howells, Kemp, & Flatt, 2018). With the growing popularity of the sport, researchers have started to investigate a number of topics applicable to Rugby Sevens. Examples of recent research into Rugby Sevens include the characteristics of players, performance indicators, training loads as well as running and cardiovascular demands on players during exercise and competition (Higham, Sabres, Pyne, & Anson, 2014; Ross, Gill, & Cronin, 2014; Suarez-Arrones, Nuñez, Portillo, & Mendez-Villanueva, 2012; Williams et al., 2018). However, to the best of the author's knowledge, only one study reported on the effects of exercise on sleep in Rugby Sevens (Leduc, Jones, Robineau, Piscione, & Lacome, 2019). This is despite the importance of sleep for sports performance which is now well recognised (Halson, 2013; Simpson, Gibbs, & Matheson, 2017). Furthermore, published research is limited on reporting training load, sleep quality and sleep quantity over a complete competitive season.

Adequate sleep is vital to human health (Watson et al., 2015a). Numerous studies have documented the harmful effect of sleep loss on animal and human well-being

(Garbarino, Lanteri, Durando, Magnavita, & Sannita, 2016; Rechtschaffen & Bergmann, 2002). The recuperative effect of sleep is influenced by both the quality of sleep as well as the duration of sleep (Wesensten, Balkin, & Belenky, 1999). It is, therefore, recommended by the Academy of Sleep Medicine and the Sleep Research Society that adults should sleep between 7 to 9 hours per night (Watson et al., 2015b), with a sleep efficiency (the amount of continuing sleep through the night without sleep disruptions) of 85% or more (World Health Organization, 2004). It is likely that because of frequent high-intensity training and competition, athletes need more sleep than non-athletes to ensure adequate recovery from training (Lastella, Roach, Halson, & Sargent, 2015). Poor sleep may hinder recovery after a match and a continuation thereof add to the stress that is already imposed by exercise (Nédélec, Halson, Abaidia, Ahmaidi, & Dupont, 2015). This is concerning as it has been shown that elite athletes often sleep poorly (Gupta, Morgan, & Gilchrist, 2017).

Optimal sleep is essential for elite athletes. During sleep, the body is in an anabolic state during which active processes take place to recover from wakefulness or prepare for the wakeful period to come while maintaining normal physiological functions (Beersma, 1998; Marshall & Turner, 2016; Oswald, 1976). Furthermore, sleep is required in athletes for high levels of mental and physical performance, recovery and prevention of exercise-induced diseases (Chennaoui, Arnal, Sauvet, & Leger, 2015; Venter, 2012). Sleep is likely the single most important recovery technique available (Halson, 2008), yet it is still not prioritised as a prominent recovery modality (Simpson et al., 2017) with most athletes not sleeping as recommended (Venter, Potgieter, & Barnard, 2014).

Studies show sleep deprivation can have detrimental effects on performance in athletes (Halson, 2013). Athletes may experience poor sleep due to numerous factors such as anxiety (Ehrlenspiel, Erlacher, & Ziegler, 2018; A. Silva et al., 2012), caffeine intake (Drake, Roehrs, Shambroom, & Roth, 2013), circadian desynchronization (Golombek et al., 2013), jet lag (Souissi, Sesboüé, Gauthier, Larue, & Davenne, 2003; Waterhouse, Reilly, Atkinson, & Edwards, 2007), late-night matches (Nédélec et al., 2015), exposure to bright light at night (Cajochen et al., 2011), noise (Venter et al., 2014) and exercise (Killer, Svendsen, Jeukendrup, & Gleeson, 2017). This is concerning as optimal sleep is critical in regulating physiological (Dattilo et al., 2011; Van Cauter, Spiegel, Tasali, & Leproult, 2008) and neurological (Frank & Cantera, 2014; Wang, Grone, Colas, Appelbaum, & Mourrain, 2011) processes. In addition, disrupted sleep on the night prior to competition can negatively impact a competitor's mood state (Lastella, Lovell, & Sargent, 2014).

A reciprocal relationship between exercise and sleep has been established (Chennaoui et al., 2015). Frequent exposure to high training loads, in order to prepare for competition demands, may have a negative influence on subsequent sleep (Killer et al., 2017). This bidirectional relationship between exercise and sleep is important to understand as poor sleep could have adverse effects on an athlete's performance (Kline, 2015).

Despite this evidence, the effect of exercise on sleep is still debated in sport science literature. Studies showed exercise to have an effect on subsequent sleep (Baekeland & Lasky, 1966; Davenne, 2009; O'Donnell, Beaven, & Driller, 2018). Epidemiological studies showed acute and chronic exercise to promote sleep (Driver & Taylor, 2000), in contrast, other studies showed high training demands to cause sleep disturbance among athletes (Gupta et al., 2017; Shapiro, Bortz, Mitchell, Bartel, & Jooste, 1981). Furthermore, the effect of exercise on sleep is contradicting as on the one hand, studies found periods of high training loads in athletes to decrease sleep duration and sleep quality (Shapiro et al., 1981; Teng, Lastella, Roach, & Sargent, 2011; Thornton et al., 2016) while on the other hand, studies found no change in sleep quality with altered duration and intensity of exercise (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018; Myllymäki et al., 2012). Thus, exercise might be beneficial in promoting sleep, but the opposite might also be true, as there seems to be a threshold where strenuous exercise disrupts sleep (Driver & Taylor, 2000). This being said, among elite athletes, the impact of daily variation in training load on the sleep quality and quantity has not been studied adequently to provide univocal evidence of the impact thereof (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018).

Even though team sport athletes seem to sleep longer than individual athletes, both groups sleep below the recommended sleep limit of eight hours per night (Lastella, Roach, Halson, & Sargent, 2015). It should be noted that guidelines regarding optimal sleep for competitive athletes are vague and difficult to prescribe as sleep among individuals differ and sport demands vary across different sports (Kirschen, Jones, & Hale, 2018; Watson, 2017).

Numerous ways to measure sleep quality and quantity have been used in sports. Although measuring sleep using PSG (Polysomnography) is still the gold standard of sleep monitoring, this is not practical in a day-to-day athletic environment (Leeder, Glaister, Pizzoferro, Dawson, & Pedlar, 2012). Wrist-watch actigraphy is a popular method of measuring sleep objectively in athletes, however, limitations include different manufacturers applying different algorithms to quantify measurements as well as misclassification of wakefulness and sleep (Karlen, Mattiussi, & Floreano, 2008; Krystal & Edinger, 2008). Subjective sleep scoring is inexpensive and easy to administer. It has been shown to be a reliable method of monitoring sleep without differing significantly from PSG or actigraphy (Caia, Halson, Scott, & Kelly, 2017; Kushida et al., 2001). Subjectively monitoring of perceived sleep of athletes adds ecological validity as it is recorded in the natural environment of an athlete.

Training load has been shown to be a valid method of quantitating exercise training (Foster, 1998). Session RPE (or training load for the purpose of this thesis) is calculated using RPE scores of an exercise to measure the internal loads perceived by athletes during a training session and has been shown to be reliable (Herman, Foster, Maher, Mikat, & Porcari, 2006). Due to the ease of use of training load in monitoring athletes during exercise, this is one of the most frequently used methods (Cardinale & Varley, 2017).

Regardless of these studies into physical exercise and sleep, there is still a void in the literature as the effect of exercise on sleep is not well understood (Killer et al., 2017; Uchida et al., 2012), especially in team sports such as Rugby Sevens. The only study on training load and Rugby Sevens showed sleep quality and quantity to be impaired during the week with the highest training load compared to the week with the lowest training load (Leduc et al., 2019).

The day to day variability in training load refers to the different training load scores between days. The effect of the day to day variability in training load on sleep experienced by athletes is an important field to be explored further. Even though many factors influence sleep on athletes (Juliff, Halson, & Peiffer, 2015; Pitchford, Robertson, Sargent, Bishop, & Bartlett, 2017; N. S. Simpson et al., 2017), the effect of exercise on sleep among elite athletes is crucial to understand as this might be one variable that trainers can control or prepare for in a competitive season (Kirschen et al., 2018). This is helpful for careful consideration of training plans, optimise performance, well-being and to avoid overtraining (Watson, 2017). If the relationship between training and sleep can be understood and can be well-managed, athletes will be able to recover better and perform at their peak. However, to further achieve the understanding of training and sleep, training load with sleep quality and quantity will have to be monitored longitudinally.

1.2 Problem statement and motivation

Due to the international popularity of Rugby Sevens and its inclusion in the Summer Olympic Games, pressure on players to perform has increased (Williams et al., 2018). The sport has become more competitive and concurrent. With that, the demands on players have become more. Travelling over multiple time zones, the tournament structure of multiple matches on a day, as well as performing under pressure have physiological and psychological effects on players well-being which negatively affects sleep and increase fatigue (Kruyt & Grobbelaar, 2019). However, an increase in training load to prepare the athlete for competition demands might have detrimental consequences and should be monitored longitudinally (Bourdon et al., 2017). Longitudinal studies showed an increase in training load to be associated with injury (Jones, Griffiths, & Mellalieu, 2016). Another consequence is the impact increased training volume and intensity has on the athlete's sleep quality and quantity. The impact of day-to-day variation in training load on sleep quality and quantity during a competitive season is unexplored in Rugby Sevens. This is crucial to understand as the reciprocal effect of sleep and exercise has been shown (Chennaoui et al., 2015). Tournaments in Rugby Sevens also poses other unique challenges to players such as frequent inter-continental travelling. This is in contrast to the usual format of home and away games in other sports. All tournaments are played away from the home country except for 10 teams which will host one tournament in their home country. This has a significant impact on the circadian rhythm of players and might influence their sleeping patterns and subsequent performance (Manfredini, Manfredini, Fersini, & Conconi, 1998). Furthermore, multiple matches being played per day, as well as the intensity and physicality of the game, make recovery critical. The importance of the restorative effects of good quality and quantity sleep on sports has been emphasised (Swinbourne, Miller, Smart, Dulson, & Gill, 2018). However, the impact of training, captain's runs and matches on sleep in Rugby Sevens is less understood. The findings from the current study will help coaches and trainers to have a better understanding of the role of exercise and sleep on the performance of players and should assist to better prepare the team for competitions. The study should also make a contribution to advance research knowledge in this field.

1.3 Aims, Objectives and Hypotheses

Research question one

Is there a relationship between training load and sleep quality and quantity in professional Rugby Sevens players over a competitive season?

Research aim one

The primary aim of this research was to determine a relationship between perceived training load and self-reported sleep quality and quantity in professional Rugby Sevens players over a 31-week competitive season.

Objectives

The objectives that guided the research for aim one was to determine the relationship between

a) daily self-reported **sleep quality** and perceived **training load** (AU) of
   - training
   - captain's runs
   - matches

b) daily self-reported **sleep quantity** and perceived **training load** (AU) of
   - training
   - captain's runs
   - matches

c) daily self-reported **sleep quality** and **duration** (in minutes) of
   - training
   - captain's runs
   - matches

d) daily self-reported **sleep quantity** and **duration** (in minutes) of
    - training
    - captain's runs
    - matches
e) daily self-reported **sleep quality** and **intensity** (RPE) of
    - training
    - captain's runs
    - matches
f) daily self-reported **sleep quantity** and **intensity** (RPE) of
    - training
    - captain's runs
    - matches

Hypotheses

It was hypothesised that

a) higher perceived training loads (for training, captain's runs and matches) will result in lower self-reported sleep quality and quantity.

b) higher perceived exercise intensity (in training, captain's runs and matches) will result in lower self-reported sleep quality and quantity

c) longer exercise duration (in training, captain's runs and matches) will result in lower sleep quality and quantity.

Research question two

Is there a relationship between sleep quality and quantity in professional Rugby Sevens players over the course of a competitive season?

Research aim two

The secondary aim was to investigate a relationship between self-reported sleep quality and quantity in professional Rugby Sevens players over a 31-week competitive season.

Hypotheses

It was hypothesised that shorter self-reported sleep duration (quantity) will result in lower perceived sleep quality in Rugby Sevens players during a competitive season.

Research question three

Does the perceived training load of professional Rugby Sevens players change over the course of a competitive season?

Research aim three

Research aim three was to determine the perceived training load of a 31-week competitive season in professional Rugby Sevens players.

Objectives

The objectives that guided the research for aim three was to determine the perceived training load (TL) of

a) training sessions (TL = sRPE of training session x the duration in minutes of the training session), reported in arbitrary units (AU).
b) captain's runs (TL = sRPE of captain's run x the duration in minutes of captain's run), reported in arbitrary units (AU).
c) matches (TL = sRPE of matches x the duration in minutes of matches), reported in arbitrary units (AU).

Hypothesis

It was hypothesised that professional Rugby Sevens players will report significantly lower perceived training loads at the end of the competitive season compared to the beginning of the season.

Research question four

Does the sleep quality and quantity of professional Rugby Sevens players change over the course of a competitive season?

Research aim four

Research aim four was to investigate the perceived sleep quality and quantity in professional Rugby Sevens players over 31-week competitive season.

Objectives

The objectives that guided the research for aim four was to determine, over a 31-week period

a) daily self-reported sleep quality (on a 10-point scale).

b) daily self-reported sleep quantity (in hours and minutes).

Hypotheses

It was hypothesised that

a) professional Rugby Sevens players will report significantly lower sleep quality at the end of the competitive season compared to the beginning of the season.

b) professional Rugby Sevens players will report significantly lower sleep quantity at the end of the competitive season compared to the beginning of the season.

Variables

Independent Variables

- Training load, intensity and duration
- Training loads during competition.

Dependent Variables

- RPE score
- Duration of training sessions, captain's runs and match played time.
- Sleep quality and quantity ratings.

Delimitations

- Players must be men.
- All players must be elite professional rugby players
- All players must form part of the South African Rugby Sevens training squad.

Assumptions

a) Players do not have any clinically diagnosed sleep disturbances.

b) RPE

i. All RPE scores of the players will be recorded after each session

ii. The players will give RPE scores truthfully

c) The data collected from questionnaires are honest and to the best of the player's knowledge

d) Training load is a true reflection of the player's workload during training or matches

e) Subjective sleep scores

  i. Are reported truthfully
  ii. Will be collected after each night of sleep
  iii. Will be answered truthfully
  iv. Are a true reflection sleep quality and quantity perceived by the player for the night as reported

1.4 Outline of the thesis

Chapter Two contains the theoretical background for the current study by reviewing relevant literature on the relationship between exercise and sleep in athletes. Furthermore, an overview of Rugby Sevens will be given to better understand this popular sport. In Chapter Three, the detailed methods of data collection are explained, while Chapter Four contains the results of the current study. Finally, in Chapter Five a discussion of the main findings is done. This chapter will also include the overall conclusion to the study, limitations of the study and recommendations for future research. The referencing style used in the current study is the style from Mendeley Desktop's reference library.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides insight into the literature on sleep and exercise to better understand the role of sleep on sports as well as in everyday life. A special focus was placed on the relationship between exercise and sleep. This chapter is divided into three sections. The first section (SECTION A) of this chapter is an overview of sleep, the function of sleep and theories on sleep. Also, an investigation of how sleep manifests in humans by first understanding the circadian rhythm and then the physiology of sleep and wakefulness were included in this section. Section two (SECTION B) of this chapter provides a detailed overview of sleep among the athletic population. In the first part of section two, training load (TL) and its different components in relation to training and recovery were discussed. In the second part of this section, the effect of sleep and exercise on performance were explored as well as sleep on athletes and team sports. In the third part, the effects of exercise on sleep were investigated. The fourth section (SECTION D) is dedicated to Rugby Sevens, the game, the characteristics of players, tournaments and training demands and why it was important to investigate sleep in this specific population. This chapter should provide a better understanding of sleep in humans as well as sleep in the athletic population and more specifically sleep in team sports. Gaps in the literature in this field will also be highlighted to motive the reason for the importance of this study.

SECTION A: SLEEP IN HUMANS

2.2 The role of sleep in human well-being

The function of sleep

Sleep is a major physiological process (Frank, 2006). Notwithstanding the increased interest in sleep research, the true function of sleep still eludes scientists and is still debated among academics (Krueger, Frank, Wisor, & Roy, 2016). Nevertheless, it is unopposed that sleep is an essential biological need in all humans and animals (Czeisler & Gooley, 2007) and as with food and water, sleep is a necessity for human survival (Lockley & Foster, 2012; Rechtschaffen, Bergmann, Everson, Kushida, & Gilliland, 1989). Sleep is mandatory for cellular, organic and systemic functions of an organism (Dattilo et al., 2011). More recently, the function of sleep on elite sports performance gained increased attention in English literature (Donnell et al., 2018; Gupta et al., 2017).

The purpose of sleep can be vaguely explained as a recovery mechanism for previous wakefulness or to prepare for the wakeful period to come (Beersma, 1998). Sleep seems to be so common and vital that even single-cell organisms show signs of a circadian rhythm where a 24-hour day is divided into rest and activity cycles (Lockley & Foster, 2012). Sleep is defined as "… a state of reduced perceptual engagement from the environment with elevated arousal threshold…. a state of rapid reversibility" (Assefa, Diaz-Abad, Wickwire, & Scharf, 2015, p.156).

Sleep is a homeostatically regulated process, characterised by immobilisation while cognition and consciousness are suspended (Allada & Siegel, 2008; Pollak, Thorpy, & Yager, 2010; Tobler, 1995). The brain and body do not shut down during sleep, rather, active processes with important physiological functions take place during this time (Beersma, 1998; Oswald, 1976; Rechtschaffen, 1998).

In sport, the function of sleep is essential for optimal performance (Halson, 2013). Sleep deprivation can be linked to poor performance, because of psychological or physiological impairment (Marshall & Turner, 2016).

Sleep and exercise are the two main stimulants for growth hormone secretion and it has been found that the amount of secretion might be exercise intensity-dependent (Rennie, 2003; Shapiro et al., 1981). There is a strong relationship between growth hormone secretion from the pituitary gland and the onset of sleep (Pollak et al., 2010). Growth hormone is closely linked to tissue repair (Oswald, 1976), which is crucial for athletes after strenuous exercise. In 1968, Takahashi was the first to find a peak in hormones secretion 70 minutes after sleep onset. Stages three and four (which are known as ‘deep sleep’) were more favourable to growth hormone secretion (Takahashi, Kipnis, & Daughaday, 1968). Later studies confirmed these findings of growth hormone secretion peaking within 90 minutes of sleep onset. This peak is diminished if sleep does not occur. When sleep is resumed after sleep deprivation the growth hormone secretion surge is amplified. Even though the growth hormone is not sleep-dependent it is reliant on sleep for the nocturnal growth hormone surge (Davidson, Moldofsky, & Lue, 1991).

Cortisol is another important hormone that is closely associated with sleep. Cortisol inhibits anabolism in the body that is needed for recovery in athletes. Controlled by the adrenocorticotrophin hormone (ACTH), cortisol peaks in the early morning, just after awakening, with a decline during the day (Pollak et al., 2010; Wehr, Aeschbach, & Duncan, 2001). Cortisol is lowest during the first 2 hours of sleep, which makes the body during this time optimal for protein synthesis as cortisol inhibits proteins synthesis (Adam & Oswald, 1983; Wehr et al., 2001). Cortisol's pulsating rhythm continues, even with sleep deprivation and does not seem to be sleep-dependent, but cortisol's rhythm may be affected by sleep-wake cycles (Adam & Oswald, 1983; Davidson & Trewartha, 2008).

Sleep is a critical factor in the process of muscle recovery whether it is induced by exercise or injury. One other hypothesis is that the total relaxation of the muscle during REM sleep allows for an optimal period of myofiber restoration (Davenne, 2009). There are also other theories on sleep which will be discussed in the section below.

Theories on sleep

Many plausible theories have been proposed in attempts to uncover sleep's biological function in human existence, however, without consensus (Beersma, 1998; Rechtschaffen, 1998). Sleep seems to come at an enormous evolutionary cost as humans and animals are immobilised during sleeping (Assefa et al., 2015; Lockley & Foster, 2012). Also, sleep duration has been shown to increase after exhaustive exercise (Shapiro et al., 1981). Thus, many theories have been proposed, such as the evolutionary/adaptive theory, the energy conservation theory, the restoration and homeostasis theory as well as the neural plasticity and memory consolidation theory.

The *'adaptive theory'* is a popular theory suggesting sleep to be an evolutionary process mostly to 'fill up time' with no or limited physiological benefits in order to survive in nature (Assefa et al., 2015; Meddis, 1975; Rechtschaffen, 1998; Webb, 1974). One of the caveats of this theory is that when animals sleep, they are most vulnerable to predators, they cannot gather food, reproduce or protect their young (Assefa et al., 2015; Lockley & Foster, 2012). It is argued that the rebound of sleep (when sleep deprivation on one night causes an increase in sleep duration the following night) does not fit with this theory (Rechtschaffen, 1998).

The *'energy conservation theory'* suggests that energy is conserved during sleep at times when there is no need to be awake (Berger & Phillips, 1995). Oxygen consumption, heart rate, and body temperature are all lowered during sleep (Shapiro & Flanigan, 1993). However, in humans, this energy conservation during sleep is relatively small compared to wakefulness. Metabolic savings of sleep over quiet wakefulness is estimated at around 10% to 15% (Rechtschaffen, 1998). Unfortunately, energy saved is only about 80 to 130 calories per night, hardly a significant amount (Lockley & Foster, 2012). Even though this theory has some merit, this does not seem to be sleep's only purpose.

The *'restorative and homeostatic theory'* might be the best related to sport and exercise. Many restorative benefits of sleep after exercise have been explored in the literature. In 1976, Ian Oswald wrote a paper on the restorative process that occurs during sleep (Oswald, 1976). This gave evidence of synthetic processes for growth being enhanced during sleep. The (rapid eye movement) REM sleep stage seems to advance synthetic processes in the brain. Other evidence that supported this theory was the rebound of sleep during sleep deprivation and the increase of (non-rapid eye movement) NREM after strenuous physical exercise (Lockley & Foster, 2012). The decrease in oxygen consumption during deep sleep might be an indication of the body being in an anabolic state (Shapiro & Flanigan, 1993). Furthermore, an increase in growth hormone secretion and a decrease in cortisol secretion during sleep after exercise is supportive of the restorative theory (Assefa et al., 2015). The growth hormone is known for its role in the anabolism of body tissue (Oswald, 1976; Takahashi et al., 1968). In contrast, cortisol is known to inhibit protein synthesis (Adam & Oswald, 1983). After the first two hours of sleep, cortisol is at its lowest, placing the body in an optimal anabolic state (Davidson et al., 1991). Another argument in favour of the restorative theory for exercise and sleep was a study in animals showing that cell mitosis peak during sleep (Adam & Oswald, 1983). Furthermore, sleep has been found to be essential in cerebral glycogen store replenishment when depleted during the waking period (Benington & Heller, 1995). Also, sleep seems to play a vital role in sports during the recovery process after exercise. During sleep, muscle glycogen is replenished and muscle damage is repaired. After sleep, alteration in cognitive function and decreased mental fatigue is evident in athletes (Nedelec, Aloulou, Duforez, Meyer, & Dupont, 2018).

Sleep is not only time for the body to recover, but is also when waste products from cells in the brain are being removed (Xie et al., 2013). The brain does not contain a lymphatic system as the rest of the body. In the brain, waste products are cleared through a system called the glymphatic system, serving the same purpose as the lymphatic system (Iliff, Goldman, & Nedergaard, 2015). A study on mice has shown that sleep increased the interstitial space in the brain by 60% allowing greater exchange of the cerebrospinal fluid with interstitial fluid. This increase the clearance of ß-amyloid, a protein that is known to build-up in the brain during wakefulness. ß-amyloid has been linked to neurodegenerative diseases (Xie et al., 2013). This showed that not only the body is restored during sleep, but also the brain (Krueger et al., 2016). It should also be mentioned that the immune system benefits from sleep as an ill person requires more sleep to conserve energy when the demand is high to assist in healing (Krueger et al., 2016).

Lastly, the '*neural plasticity and memory consolidation theories'* are also popular, suggesting cognitive functions to be maintained by neural connections that are formed during REM sleep. This theory proposed that it is rather the brain than the body that recuperates during sleep (Shapiro & Flanigan, 1993). Many studies reviewed synaptic plasticity during sleep and concluded that consolidation of declarative memories is a sleep-dependent neurobiological process and that neural maintenance is facilitated by sleep (Ellenbogen, Payne, & Stickgold, 2006; Roth, Rattenborg, & Pravosudov, 2010; Wang et al., 2011). It would make sense that the time during sleep would be preferable for memory consolidation when energy demands and external sensory stimulation are lowest (Lockley & Foster, 2012). Unconsciousness during sleep thus prevent behaviour that would hinder the proper functioning of these neural process changes in the brain (Krueger et al., 2016). It is also plausible that to transfer short-term memories to long-term memory, the temporary memory needs to be “shut-off” to avoid interruptions (Wang et al., 2011). The positive effect of sleep on memory, as well as sleep-promoting synaptic plasticity in the brain has been well-documented (Assefa et al., 2015; Frank & Cantera, 2014).

A brief history of sleep research

Human sleep has fascinated humankind through the ages (Ferrie, Kumari, Salo, Singh-Manoux, & Kivimäki, 2011; Pollak et al., 2010). English literature indicates the first documented medical theory on the function of sleep to be credited to Alcameon from Crotona around 500 B.C. (Pollak et al., 2010). The Greek, Hippocrates (460 B.C.) noticed that while sleeping the body felt cool to touch, an observation that would be confirmed by modern medicine centuries later (Pollak et al., 2010; Quan, 2012). The earliest documentation on the duration for healthy sleep comes from the Jewish physician Moses ben Maimon (1135 -1204 A.D.) who prescribed eight hours per night to be sufficient (Pollak et al., 2010). During the late 1960s, the first study on the relationship between exercise and sleep was published by Frederick Baekeland and Richard Laskey (Baekeland & Lasky, 1966; Uchida et al., 2012).

It is evident that sleep epidemiological studies gained interest in recent years (Ferrie et al., 2011). A recent search on PubMed’s database with the keyword ‘sleep’ showed a dramatic increase in publications on sleep with 15 226 publications in 2019 alone totalling to more than 200 000 publications in the last 70 years (see Figure 2.1). This is an indication that the fascination with sleep has only increased in later years.

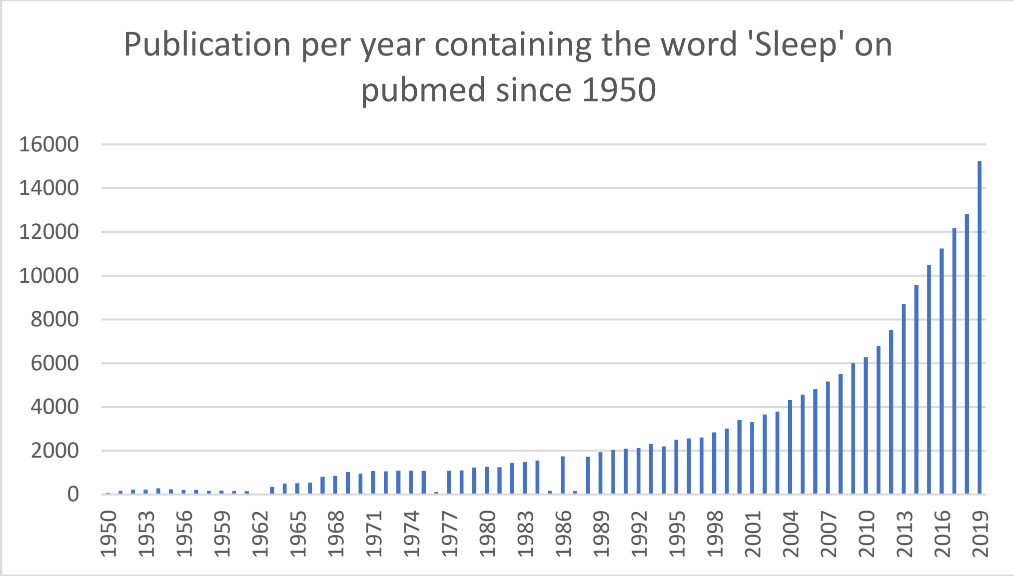


Figure 2.1 *The increase in publications since 1950 on PubMed with the keyword 'sleep'.*

2.3 Amount of sleep required in humans

A decline in sleep duration over the past century is evident in the general population. Before the invention of the light bulb in 1910 people slept for around 9 hours each night (Coren, 1998). Today adults sleep only around 7.5 hours per night. This is as a result of being a 24-hour society and shift work in the night (Pickering, 2006). A study done from 1991 to 2012 in adolescents in the USA showed a decrease in adolescents sleeping more or equal to seven hours per night (Keyes, Maslowsky, Hamilton, & Schulenberg, 2015). In 2015, the Academy of Sleep Medicine and the Sleep Research Society released a joint consensus on the recommendation of the amount of sleep needed for optimal health in the general public. In their report they recommend seven or more hours per night and warned that sleeping less than seven hours might have adverse health outcomes such as weight gain, obesity, diabetes, hypertension, heart diseases, and stroke, depression and an increase in mortality risk. Likewise, they warned that less than seven hours of sleep per night might also negatively impact immune function, increase the perception of pain, impair performance, increase cognitive errors and enhance the risk for accidents (Watson et al., 2015a).

However, it is argued that when humans choose to sleep freely, a longer duration of sleep is exhibited. As early as the 1980's research reported on sleep in humans without external time-cues (Zulley, 1980). Free-running versus controlled experiments showed that when subjects were measured in a laboratory under normal conditions they slept for 7.26 ± 0.86 hours, but subjects living in an underground apartment isolated from time cues and social interaction slept for 8.83 ± 2.7 hours a day (Zulley, 1980). In Antarctica, day and night are separated by a season, but studies in humans where circadian rhythms were allowed to run free, showed less variation to normal conditions and remained around eight hours of sleep per night (Yoneyama, Hashimoto, & Honma, 1999). It seems that even though sleep duration can be adjusted when time-cues are eliminated, human circadian rhythm still closely resembles a period slightly longer than 24 hours (Dijk & Lockley, 2002).

Quality and quantity of sleep in the athletic population

It is suggested that elite athletes require a greater amount of sleep to be able to recover sufficiently from injury, training and competition (Marshall & Turner, 2016; Shapiro et al., 1981) as sleep deprivation is detrimental to sports performance (Marshall &

Turner, 2016; Reilly & Edwards, 2007; Temesi et al., 2013). It is thus concerning that sleep in elite athletes have been shown to be poor, with low subjective sleep quality and in some cases border-lining with insomnia symptoms (Gupta et al., 2017). Athletes are often not exposed to optimal sleeping conditions, yet little research has been conducted on the sleep behaviour of athletes. Despite numerous studies highlighting the dependence of athletes' performance on sleep, there are currently no accepted guidelines regarding sleep for competitive athletes (Kirschen et al., 2018; Watson, 2017). Also, pre-competitive sleep's impact on mood and performance is largely unexplored (Lastella et al., 2014). One study revealed the sleep duration of the athletic population to be similar to the general public (Martin, Arnal, Hoffman, & Millet, 2018). Other attempts have been made to establish normative sleeping parameters for the elite athletic population, but the reported values are widespread. The reasons for this might be the difference in definitions used such as 'sleep duration' and 'time in bed'. Differences can also be attributed to the methodologies used as it was found that perceived sleep scoring overestimated sleep duration compared to objective measurements such as actigraphy by 19 minutes (Caia et al., 2018).

After assessing sleep on athletes one study found normative sleep duration for elite athletes to be 07:50 ± 01:08 hh:mm (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). Another study monitoring Olympic athletes showed different results with time in bed averaging 08:26 ± 0:53 hh:mm and total sleep time at 06:55 ± 0:43 hh:mm (Leeder et al., 2012). Studying the sleep behaviour of youth elite athletes (18.8 ± 3.0 years) from various sports including individual and team sports, the average daily self-reported sleep during the night was 08:11 ± 0:45 hh:mm. Using the Pittsburgh Sleep Quality Index 40 of the 98 athletes (41%) were classified as poor sleepers. Self-reported sleep quality was reported as 6.84 ± 0.92 on average on a 1-10 scale where 10 was the highest perceived sleep quality (Knufinke, Nieuwenhuys, Geurts, Coenen, & Kompier, 2018).

Many elite athletes experience sleep disturbances when travelling (Kruyt & Grobbelaar, 2019). Travel and training are the most likely to disturb sleep quality. Almost half of the elite athletes in studies reviewed can be classified as poor sleepers (Gupta et al., 2017). Athletes experienced alternative constraints such as circadian disruptions, jet lag, changes in sleeping habits, such as sharing hotel rooms and new environments as well as sleep restriction or difficulty sleeping, because of a rigid training schedule and anxiety prior to competitions (Davenne, 2009; Simpson et al., 2017). One other unique challenge for elite athletes is fluctuation in training load which impacts sleep (Watson, 2017). Furthermore, there is evidence that extended sleep might be beneficial for athletic performance (Mah, Mah, Kezirian, & Dement, 2011).

Although the understanding of sleeping habits in team sports are poor, there is evidence of a reduction in sleep quality and duration during and after a competition (Fullagar, Duffield & Skorski et al., 2015). One study compared sleeping behaviour between individual and team sport athletes. Of the 124 elite athletes, 66 were from individual sports and 58 from team sports. They were monitoring using sleep diaries and wristwatch actigraphy for at least seven days. Results showed that although individual sport athletes go to bed earlier, their sleep duration was less than that of team sports athletes, 6.5 and seven hours respectively. Both groups slept for less than the recommended eight hours of sleep. Sleep efficiency of individual sport athletes was poorer than team sport athletes, although subjective sleep quality did not differ between individual and team sports (Lastella, Roach, Halson, & Sargent, 2015).

The sleep of elite rugby union players' (n = 28) was monitored before and after matches using actigraphy wristwatches to assess the impact of competition on sleep. Each player was monitored for two days prior to the match and three days post-match. This showed an increase in sleep duration leading up to a match with a decrease the nights following the match. The increase in sleep prior to a match can be attributed to players being aware of a good night's rest prior to a game to increase performance, whereas high cortisol levels and socialising after matches contribute to less sleep after matches. Looking at post-match sleep latency, sleep efficiency and fragmentation index showed substandard sleep quality for athletes. This varies largely between individuals and further investigation revealed that some of the players experienced sleep disruption (Shearer, Jones, Kilduff, & Cook, 2015). There is evidence of better race finish times with longer pre-race sleep duration for ultramarathon runners (Martin et al., 2018).

The literature on sleep behaviour of athletes before a competition is contradicting. It is widely accepted that obtaining optimal sleep the day before the competition is important. Further, it has been reported in the literature that recommended sleep quality and quantity the night prior to competition might be difficult to achieve. Numerous studies showed sleep being better the night prior to competition than the night after the competition (Roberts, Teo, & Warmington, 2019). Specifically, in elite rugby union players it was found that sleep duration the night prior to competition was increased (Shearer et al., 2015).

Monitoring the sleep behaviour of professional team sports athletes (n = 51) from three different team sports for at least seven days, it was found that compared to soccer and rugby union, Australian Rules football players have the lowest sleep quality (Miller et al., 2017). This is interesting as Australian Rules is a hybrid between rugby union and soccer. Australian Rules football players cover more distance (12.6 km) in a match than rugby union (6 km) and soccer players (10 km). Even though Australian Rules football players have fewer collisions between players in a match than rugby union, it is significantly more than in soccer. These collisions between players and the greater amount of distance covered during matches may account for the lower sleep quality in Australian Rules football players (Miller et al., 2017).

In contrast to evidence of increased sleep duration before competition, Ehrlenspiel and colleagues (2018) found 79 elite male athletes from various sports reported subjective sleep quality to deteriorate in the days leading up to the competition, the lowest being the night before the competition. Cognitive anxiety prior to the competition was linked to poor subjective sleep ratings (Ehrlenspiel et al., 2018). Another study also showed sleep loss to be common with athletes prior to competitions. In a study monitoring 103 German athletes the night prior to a marathon, 70% of the athletes reported having slept worse than usual. The most prevalent reason for this was anxiety (21%), noise (15%) and toilet visits (14%) during the night. The participants completed a BRUMS (Brunel Mood Scale) questionnaire the morning of the race and it revealed that the negative mood states of fatigue and tension were both negatively correlated with sleep quality and total sleep time. Tension was positively correlated with the number of awakenings. Vigour was positively correlated with sleep quality. Athletes only reported an average of 5h51min ± 1h25min total sleep time. However, in this study, the quality of their sleep did not influence performance. It was concluded that disrupted sleep on the night prior to competition can negatively impact a competitor's mood state (Lastella et al., 2014). During a survey of 636 ultramarathon runners 55% runners indicated that the use of sleep extensions prior to the race was the most important sleep strategy (Martin et al., 2018). A study on individual cyclists showed sleep to be higher the night after competition compared to the night prior to competition (Lastella, Roach, Halson, Martin, et al., 2015). Another group of ultra-marathon runners reported the night with the longest duration of sleep time to be the night two days after the competition (Shapiro et al., 1981).

Silva et al. (2012) monitored Brazilian Paralympics athletes (n = 27) before the 2008 Beijing Paralympic Games using sleep questionnaires 10 days before the competition. It was alarming that 83% of the athletes had poor sleep quality. Most (71%) of the athletes were morning-type and the authors concluded that this should be considered when scheduling rest and training times (Silva et al., 2012). A survey study of 283 Australian athletes from team and individual sports showed that 64% experience sleep problems the night prior to competition. This was attributed to nervousness and thoughts regarding the competition. Of those who experienced sleep problems, 46.6% reported this to have no perceived influence on performance, however, 42.1% did indicate increased daytime sleepiness. Concerningly, only 14% of all the athletes believed reduced sleep resulted directly in a worse performance. In this study, there was no difference in sleep problems reported between team or individual sports, however, it did show individual athletes had a greater number of strategies to overcome sleep disturbances compared to team sport athletes.

2.4 The consequences of sleep deprivation

Sleep deprivation is linked to many adverse health outcomes (Garbarino et al., 2016). There is evidence that the mortality rate in humans may be closely linked to hours of sleep. In 1964 Hammond published one of the first studies in the English literature showing a U-shape relationship between sleep duration and mortality rate. It was found that seven hours of sleep per night was associated with the lowest mortality rate and less than five hours or more than 10 hours of sleep per night was associated with the highest mortality rate (Hammond, 1964). Since Hammond's publication, other research confirmed support for the U-shape association between sleep length and mortality, showing people sleeping more than 8 hours (long sleepers) and people sleeping less than seven hours (short sleepers) are at a higher risk of death than those sleeping between seven and eight hours (Hublin, Partinen, Koskenvuo, & Kaprio, 2007; Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002).

Cardiovascular diseases such as coronary heart disease and stroke have been linked to a higher risk in both short and long sleepers (Cappuccio, Cooper, Elia, Strazzullo, & Miller, 2011). A U-shaped relation between sleep duration and hypertension was also found in a survey study of more than 5000 participants. It was found that subjects sleeping less than seven hours and more than eight hours per night had an increase in the odds ratio for hypertension (Gottlieb et al., 2006) with the worst hypertension found in subjects sleeping less than five hours (Gangwisch et al., 2006). Not all studies agree, as one study found that even though there is an increased risk in fatal strokes with long or short sleep, this is not significant if corrected for other variables such as BMI, smoking habits, hypertension and other health factors (Helbig, Stöckl, Heier, Ladwig, & Meisinger, 2015).

Extensive literature reviews have been done on the negative effects of sleep loss and metabolic diseases (Knutson, Spiegel, Penev, & Van-Cauter, 2007), immune and hormonal dysregulation (Aldabal & Bahammam, 2011; Maurovich-Horvat, Pollmacher, & Sonka, 2008), insulin resistance and type II diabetes (Spiegel, Knutson, Leproult, Tasali, & Van Cauter, 2005), increased BMI, elevated ghrelin and reduced leptin hormones (Taheri, Lin, Austin, Young, & Mignot, 2004) and weight gain (Patel & Hu, 2008).

Sleep loss has been shown to decrease insulin sensitivity, resulting in impaired glucose tolerance and increased diabetes risk in men and women (Morselli, Leproult, 2010; van Leeuwen et al., 2010). Carbohydrate metabolism is adversely influenced by sleep deprivation and sleep seems to help control blood glucose levels (Van Cauter et al., 2008). Sleeping less than six hours per night has been identified as a risk factor for developing type II diabetes (Yaggi, Araujo, & McKinlay, 2006) with one study showing people sleeping less than five hours per night had double the risk of developing diabetes than people sleep seven hours per night (Gangwisch et al., 2007). Insulin resistance could be observed after as little as only one night of partial sleep deprivation as healthy subjects who were only deprived of four hours of sleep showed a significant decrease in insulin sensitivity (Donga et al., 2010). It is also very important to note that it might not only be sleep loss that can have a negative effect on metabolism, but also circadian misalignment that is common in shift workers or jet lag experienced by athletes crossing multiple time zones for competitions (Leproult, Holmbäck, & Van Cauter, 2014).

Extreme total sleep deprivation is associated with serious negative consequences. Total sleep deprivation killed rodents within two weeks (Rechtschaffen et al., 1989). Rodents survive for 16 to 54 days when paradoxically sleep-deprived (only deprived of REM sleep) indicating the importance of the different sleep stages (Rechtschaffen & Bergmann, 2002; Rechtschaffen et al., 1989). This is also evident in humans in the cases where a sleep sickness called fatal familial insomnia is diagnosed and the patient cannot fall asleep and suffers from chronic insomnia, which leads to dementia and ultimately death (Pollak et al., 2010). The effects of sleep deprivation are so strong that it is used as a torture and interrogation tactic (Lockley & Foster, 2012). Fortunately, cases of total sleep deprivation for extended periods in sports are rare, but as shown above, acute sleep loss can have adverse health outcomes.

The consequences of sleep deprivation on sport performance

Sleep deprivation has been shown to have detrimental effects on the performance of athletes (Halson, 2013). Sleep deprivation can be linked to poor performance due to psychological or physiological impairment (Marshall & Turner, 2016). Two distinct outcomes of total sleep deprivation are evident, namely an increase in catabolic hormones such as cortisol and changes in the secretion patterns of anabolic hormones such as testosterone (Dattilo et al., 2011). Depending on the required energy sources systems, sleep deprivation seems to affect sports performance differently. Previous research showed aerobic activities to be more sensitive to sleep deprivation compared to anaerobic activity. Also, performance requiring tactical and/or technical skills seems to benefit most from increased sleep duration (Kirschen et al., 2018). This is supported by other studies also showing accuracy, reaction time and endurance performance to be greatly affected by a lack of sleep while anaerobic power, strength and sprint performances seem to be the least affected by a lack of sleep (Watson, 2017). Even mild sleep loss (sleeping four to five hours) can be related to a decrease in performance in speed, endurance and performance accuracy (Simpson et al., 2017).

The reason for this decline in performance is still unknown. One study showed a decrease in the distance in a self-paced treadmill distance test and a raised VO_2 on a 30 min preloaded treadmill test after 30 hours of sleep deprivation compared to a control. It should be noted that speed, RPE, core temperature, mean skin temperature, heart rate and respiratory parameters did not differ significantly between the two tests. The authors concluded that a decreased endurance performance can be seen after one night of sleep deprivation, however, pacing, cardio-respiratory and thermoregulatory were unaltered. The authors stated that a possible reason for this decline in endurance performance might be because of a similar perception of effort than the control, even though covering less distance, indicative of an altered effort of perception at a specific workload (Oliver, Costa, Walsh, Laing, & Bilzon, 2009). Another study looking at physical performance and motor control after 60 hours of sleep deprivation, found a decrease at submaximal load in heart rate, VO_2 and ventilation measurement, but remarkably all the maximal values remained unchanged. The authors discussed that the reason for these findings is poorly understood, but similar to findings in functional overreaching athletes, this might be explained as a down-regulation of the cardiovascular regulation centre (Vaara et al., 2018). Similarly, when looking at sleep deprivation and anaerobic performance tests, it was found that 24 hours of sleep deprivation did not affect power variables, but after 36 hours it had an effect. This mechanism could not be explained by the authors, but their theory was that sleep deprivation affects the higher central nervous system's cognitive centres causing accumulative central or peripheral fatigue with prolonged wakefulness (Souissi et al., 2003). A systematic review of 17 studies that met a strict inclusion criterion concluded, sleep deprivation to have only minor effects on muscle strength during resistance exercise. Maximal force output of multi-joint movement was reduced, but not of single-joint movements. Hormonal responses to sleep deprivation were mixed, therefore no conclusion could be made. (Knowles, Drinkwater, Urwin, Lamon, & Aisbett, 2018). Studying the effect of one-night sleep deprivation on university students, only reaction time to performing a task and systolic blood pressure after physical exercise showed a significant increase compared to a night of normal sleep. These results showed cognitive ability was not influenced by acute sleep deprivation. RPE and heart rate was not significantly higher, however, mean RPE was higher and heart rate after exercise was lower than compared to normal sleep nights. This might be an indication that physical ability is more impacted by acute sleep deprivation than cognitive ability (Patrick et al., 2017). Temesi et al. (2013) studied athletes after 1 night of complete sleep deprivation. Exercise time to task failure was decreased after sleep deprivation compared to the control condition and RPE scores during a 40 min submaximal exercise were higher. There were no differences in neuromuscular function after exercise, but there was an impairment of cognitive function such as reaction time. As there was no difference observed between neuromuscular function, central fatigue cannot be used to explain sleep deprivation's decrease in performance (Temesi et al., 2013).

A very plausible hypothesis is that sleep deprivation might hinder muscle recovery through inhibition of the protein synthesis pathway and an increase in the activity of degradation pathways (Dattilo et al., 2011). This was motivated by citing findings from previous studies which showed sleep deprivation caused increased catabolic hormones such as cortisol and changes in the patterns of rhythmic secretion of anabolic hormones like testosterone. More evidence is the increase in the urinary secretion of urea and muscle mass loss during experiments of sleep deprivation.

Some researchers found that sleep loss may be linked to injuries in sport, but there is no conclusive evidence of this. However, authors created a named called "fatigue-related injuries" referring to injuries occurring after six or fewer hours of sleep were obtained. Reasons for this is likely to be related to decreased proprioception and postural control (Chennaoui et al., 2015). One study showed athletes to be 1.7 times more prone to injuries when sleeping for less than eight hours. Also, it was found that illness is more prominent in short sleepers and pain threshold seem to be reduced with sleep restriction as opposed to extended sleep which raised the pain threshold (Simpson et al., 2017). In a review, Halson (2013) concluded that there are studies that found anaerobic performance to only affected after 30 hours of total sleep deprivation, while aerobic performance can be affected after only 24 hours of total sleep deprivation. Repeated bouts of exercise are impacted more than a once-off maximal exercise (Halson, 2013).

Scott and colleagues (2006) found evidence that acute sleep deprivation of 30 hours led to lower cognitive and psychomotor performance as well as mood ratings. This effect seems to be intensified by the addition of exercise when reaction times were slower and negative mood disturbances were greater (Scott, Mcnaughton, & Polman, 2006).

A positive correlation was shown between longer pre-race sleep duration and race finish times for ultramarathon runners (Martin et al., 2018). Another study where the participants were asked to complete a questionnaire showed that ultramarathon runners who increased their sleep time before the race, completed the race faster (Poussel et al., 2015).

Results in the literature are contradicting on performance decrements related to sleep loss (Fullagar, Skorski, et al., 2015). Despite a vast amount of studies reported on the importance of good sleep for optimal performance (Watson, 2017), the effect of sleep on performance in the literature is inconclusive. The literature on the effects of sleep loss on exercise and performance seem to be inconclusive in the literature with large interindividual variability (Samuels, 2009). Reasons for this may be because various exercise, frequencies, intensities and duration of the exercise were reported in the literature (Souissi et al., 2003). A systematic review investigating the impact of sleep on performance in competitive athletes across a variety of sports could not find one study that showed conclusive evidence of a decrease in performance because of reduced sleep duration. Longer sleep duration on performance did show a positive outcome on performance (Kirschen et al., 2018). Athletes improved performance by extending sleep to 10 hours a night for five to seven weeks (Mah et al., 2011).

Furthermore, it is evident that there is an association between sleep and immune function. Studies have indicated the immunosuppressive effects of sleep deprivation (Bryant, Trinder, & Curtis, 2004; Levent et al., 1999). Immune alteration after short-term high-intensity exercise and sleep deprivation are evident as Interleukin-6 (IL-6), a pro-inflammatory cytokine, increased under these conditions. Sleep deprivation seems to alter plasma concentrations of IL-6 during recovery after short-term maximal exercise (Abedelmalek et al., 2013).

As Chennaoui and colleagues (2015) mentioned, sleep deprivation on the parameters of physiology, psychology and biomechanics are poorly understood (Chennaoui et al., 2015).

2.5 Endocrinology and physiology of sleep

Sleep architecture

Sleep architecture represents the occurrence of sleep stages during the night. There is no clear marker for the exact instance of sleep onset (Carskadon & Dement, 2011).

Two distinct categories, called states, can be observed during sleep: Rapid eye movement (REM) and non-rapid eye movement (NREM) (Lockley & Foster, 2012). NREM is further sub-classified into stages 1 to 4 and more recently, N1 – N3 (Silber et al., 2007). During a night of sleep, it was observed that humans cycle through these stages in a similar pattern. A cycle consists of the start of NREM to the end of REM, this cycle lasts about 90 minutes. The cycle repeats itself usually three to five times during a night. Sleep is usually entered through NREM stage N1 and progresses to the deepest stage N3 (previously S4), before the first episode of REM. The first NREM to REM usually lasts about 70 – 100 minutes (Carskadon & Dement, 2011), but can be as quick as 40 minutes (Saper, Fuller, Pedersen, Lu, & Scammell, 2010). After the first NREM – REM cycle, the second cycle period increases to about 90 – 120 minutes. Slow-wave sleep (N3 or SWS) is usually more frequent and longer in duration in the first half of the night with its longest duration in the first third of the night. During the second half of the night REM sleep becomes more frequent and increases in length (Carskadon & Dement, 2011). Switching between stages can take a few seconds to a minute (Saper et al., 2010). Micro-arousals (or short periods of wakefulness) are also common during the night when a person will wake-up for a few seconds to a few minutes, but is unable to recall this the next morning. These micro-arousals are more frequent in the latter parts of the night and can sometimes coincide with REM sleep (Carskadon & Dement, 2011). It is believed that these micro-arousals during the night might be the body's way of "touching the surface" in order to regulate the body temperature, as the body's thermoregulatory capabilities are diminished during the other stages of sleep (Driver & Taylor, 2000).

It has also been shown that after sleep loss SWS takes priority in recovery sleep and

REM sleep only recovers the night after SWS has recovered (Carskadon & Dement, 2011). This might be an indication of the importance of SWS. This is important for athletes as studies have been conducted showing heat load and physical exercise may increase SWS during sleep (Beersma, 1998). Furthermore, Growth hormone (GH) secretion has been shown to be reliant on SWS (Takahashi et al., 1968). Even though it does not seem to be dependent on SWS, peak GH secretion is diminished if SWS is not reached (J. R. Davidson et al., 1991).

Melatonin is known as a sleep-promoting hormone and seems to act as a darkness signal to the brain. With high levels in the blood during the night and low levels during the day, melatonin is also called the 'hormone of darkness' or the 'Dracula hormone' (Brown, 1994; Lockley & Foster, 2012). Released by the pineal gland into the bloodstream, melatonin receptors on the SCN suppress firing of the SCN neurons (Lockley & Foster, 2012). Melatonin coincides with the 'sleep gate', but its release may only be an addition to sleep onset. It is likely that the circadian rhythm opens the sleep gate, switching on melatonin that helps to facilitate sleep. Melatonin effectiveness to promote sleep might be as a result of its vasodilation properties (Kräuchi & Wirz-Justice, 2001). Taking melatonin supplementation to induce sleepiness may assist in treating sleep disorders and the effect of jet-lag (Lockley & Foster, 2012).

It is also believed that adenosine, released by glial cells (a neurological cell), could signal increased sleep pressure and initiate sleep. After continual wakefulness, adenosine increases in the basal forebrain area and promotes sleep via inhibition of cholinergic basal forebrain neurons (Mignot, 2008). Adenosine act as a neurotransmitter in the central nervous system. This is of interest to athletes as glycogen depletion during wakefulness and exercise increases the synthesis and release of adenosine from (adenosine monophosphate) AMP that stimulates neuronal adenosine receptors resulting in increased sleep pressure (Benington & Heller, 1995). Caffeine is a nonselective adenosine antagonist which bind to adenosine receptors and increase wakefulness (Bjorness & Greene, 2009). It is unlikely that adenosine is the only component of sleep drive as it is only increased over certain parts of the brain during prolonged wakefulness (Saper et al., 2010).

Body temperature is likely one of the main drivers of sleep regulation. During the day, core body temperature is higher than at night (Wehr et al., 2001). Sleep onset seems to coincide with the decline of the core body temperature and wakefulness with the rising core body temperature (Cajochen et al., 2000; Waterhouse, Fukuda, & Morita, 2012). Previous studies concluded that peripheral vasodilation and drop in core body temperature is the first two physiological signs leading to nocturnal sleep (Cajochen et al., 2000). It is important to note that a reduction in core body temperature does not induce sleep, but heat loss is necessary for sleepiness (Kräuchi, Cajochen, Pache, Flammer, & Wirz-Justice, 2006). Even with a constant routine in a controlled environment without external cues, the core body temperature’s rhythm does not disappear, but may be altered (Kräuchi & Wirz-Justice, 2001). Performance such as memory, alertness, attention and reaction time has been shown to be better with higher body temperature compared to lower body temperature (Wright, Hull, & Czeisler, 2002). A meta-analysis study found that even though core body temperature correlates with sleep onset latency, the biggest relation between sleep onset latency is vasodilation causing distal skin heat loss. Nocturnal heat loss might be advanced by melatonin secretion (Kräuchi & Wirz-Justice, 2001). Other hormones such as prolactin, luteinizing and testosterone are all linked to sleep, but not dependent on any sleep stage (Oswald, 1976).

Sleep and wakefulness regulation in the brain

The brain accomplishes wakefulness and sleep by multiple neurons releasing different types of neurotransmitters and neuropeptides (Silver & Kriegsfeld, 2014). Two main neural circuits in the brain have been identified that facilitate sleep and arousal in humans. These two circuits produce sharp transitions between sleep and wakefulness through mutual inhibition and a self-reinforcing loop. This rapid transition resembles a ‘flip-flop switch’. Whenever one state starts to dominate the other, the switch is made instantaneously, thus eliminating a transitional state. A transitional state will compromise human behaviour as being asleep and awake at the same time will be inefficient and dangerous (Saper, Scammell, & Lu, 2005). Wakefulness is obtained through an ‘ascending arousal system’ (AAS) and sleep is promoted mainly via the ‘ventrolateral preoptic nucleus system’ (VLPO). These pathways are stabilised by other neurons such as the orexin neurons (also called hypocretin) (Saper et al., 2005). During wakefulness, the VLPO is inhibited (Silver & Kriegsfeld, 2014). However, during sleep VLPO inhibits AAS neuron groups as well as the orexin neurons, weakening the arousal activities and strengthening sleep consolidation (Saper et al., 2005). This is most likely regulated by the SCN and homeostatic input (Silver & Kriegsfeld, 2014). The VLPO projects to all major cell groups in the brain during sleep, inhibiting them with neurotransmitters galanin and γ-aminobutyric (GABA) (Schwartz

& Roth, 2008). Adenosine accumulation has shown to activate VLPO neurons (Gallopin et al., 2005) and inhibit orexin neurons (Bjorness & Greene, 2009).

2.6 Circadian rhythms

Since the first experiments by Jean-Jacques d'Ortous deMairan in 1729, showing a circadian rhythm in plants without light-cues (Dement, 1998), it became apparent that circadian rhythm is the driving force for sleep's rhythmically propensity. Circadian rhythms in humans can persist without time-cues with rigid precision and display a cyclic process. This oscillation might be controlled genetically by "clock genes" (Czeisler & Gooley, 2007).

Subsequent studies in humans have been performed by removing all light cues and studying endogenous circadian rhythm. Even with a forced desynchronised protocol, body temperature exhibited near 24-hour resemblance (Silver & Kriegsfeld, 2014). When studies were performed on subjects in an underground bunker with no perception of time and only exposed to dim light during wake episodes, intrinsic circadian rhythms in subjects averaged between 24.1 to 24.2 hours. Furthermore, 25% of subjects showed an intrinsic circadian rhythm of shorter than 24 hours. It is now widely accepted that the human circadian pacemaker is tightly managed to range between 23.5 to 24.7 hours (Czeisler & Gooley, 2007). The circadian rhythm is endogenous regulated and can persist without external input (Silver & Kriegsfeld, 2014; Wehr et al., 2001).

In 1982 Alexander Borbély proposed the 'two-process model' to explain the circadian rhythm (Borbély, 1982). Borbély proposed a Process S, which is a sleep-dependent homeostatic process and a Process C, which is a sleep-independent circadian process. The term 'sleep homeostasis' is used to describe the tendency to maintain sleep propensity within a certain range (Borbély, 2009). Process S responds to physiological cues for sleep whereas process C responds to environmental cues for sleep (Beersma, 1998). Process S accumulates with time awake and causes sleep pressure. It is reversed only by sleep, predominantly during slow-wave sleep (SWS) when it dissipates (Czeisler & Gooley, 2007; Waterhouse, Fukuda, & Morita, 2012). Adenosine has also been proposed to be involved in the homeostatic regulation of sleep due to its build-up in the extracellular level of the brain during wakefulness, increasing sleep pressure, and contributing to Process S (Benington & Heller, 1995; Bjorness & Greene, 2009). Process C is the rhythmic propensity to sleep and most likely controlled by a circadian oscillator. Process C displays a daily rhythm and is parallel to the rhythm of core temperature (Waterhouse et al., 2012). It is assumed that the propensity and duration of sleep are determined by the combined action of these two processes (Borbély, 1982). Sleep disturbance is notably higher when sleep is commenced at an unfavourable phase of the circadian rhythm (Tahmasian, Khazaie, Sepehry, & Russo, 1995). This circadian rhythm is synchronised each day by the Suprachiasmatic nuclei (Czeisler & Gooley, 2007).

Chronotype and sport

Humans show individual diurnal variation during the day, because of individual endogenous circadian rhythms (Roenneberg, Wirz-Justice, & Merrow, 2003). This is known as chronotype and people can be classified according to their chronotypes such as morning-type and evening-type. Some physiological processes are dependent on these circadian rhythms and have been shown to influence academic achievement, cognitive ability as well as sports performance (Preckel, Lipnevich, Schneider, & Roberts, 2011; Rae, Stephenson, & Roden, 2015; Tonetti, Natale, & Randler, 2015). Circadian rhythms seem to affect the athlete and the outcome of sports performance, (Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005) so much so, that it might even influence the type of sport that is selected by the athlete (Lastella, Roach, Hurem, & Sargent, 2010).

Furthermore, it is believed that performance is dependent on the circadian rhythm which is closely associated with an individual's daily core temperature rhythm. Morning-types have a higher oral temperature on awakening and throughout the day, but this is surpassed by evening-types in the evening whose oral temperature only peaks later in the day after morning-types oral temperature already decreased (Horne & Ostberg, 1976). It has also been found that saliva cortisol is significantly higher on awakening in morning-types which might explain the higher alertness in the morning (Kudielka, Federenko, Hellhammer, & Wüst, 2006).

Fraser-childs and Brandstaetter (2015) investigated the circadian phenotype of athletes and concluded that the time since awakening is a stronger predictor of performance than the time of day of the performance. They found morning and intermitted types to peak around 5.5 and 6.5 hours after awakening with evening types only reaching a peak performance after 11 hours after entrained awakening (Facer-Childs &

Brandstaetter, 2015). Reviewing the literature, it was concluded that chronotype might have an influence on the performance of an athlete with regards to training time of day as well as competition time of day and this is something that should be kept in mind by coaches (Roden & Rae, 2017).

Suprachiasmatic nuclei (SCN)

Humans are extremely sensitive to light as circadian synchroniser. Since it became apparent that light is the primary circadian synchroniser in mammals, the SCN of the hypothalamus has become known as the master circadian clock (Duffy, Kronauer, & Czeisler, 1996). It is responsible for generating and syncing of the circadian rhythms and is the central neural pacemaker of the body (Czeisler & Gooley, 2007). The SCN is synchronised to environmental light and dark cycles and control the clocks in body tissue and organs. Biological processes in the body do not have access to external light and are thus reliant on the SCN to regulate and communicate this light information (Silver & Kriegsfeld, 2014). The SCN also controls hormonal rhythms such as melatonin and cortisol (Dijk & Czeisler, 1995).

The SCN is made up of 20 000 cells and forms a highly organized network that projects to numerous nearby hypothalamic regions (Silver & Kriegsfeld, 2014). The SCN is impacted by zeitgebers (German for time giver) in this case light (Waterhouse et al., 2012). The SCN is also a regulator for circadian gene transcription, a major component of the biological clock in the body (Silver & Kriegsfeld, 2014).

2.7 Tools used to measure sleep characteristics

Polysomnography (PSG)

Polysomnography (PSG) is regarded as the “gold standard” to objectively measure brain activity during sleep (Kushida et al., 2001). It is used to accurately identify the different sleep stages. PSG’s main components consist of EEG (electroencephalogram) placed on the scalp, electromyography (EMG) placed on the chin to measure muscular activity, electrooculogram (EOG) placed near the eyes to measure eye movement and EKG (electrocardiogram) for heart rate measurements (Kushida et al., 2001; Lockley & Foster, 2012; Silber et al., 2007). Using PSG is expensive and unpractical in sports teams especially for longitudinal studies.

Actigraphy

A method of measuring sleep in sports teams that has recently gained popularity is to measure sleep using motion actigraphy. Measuring sleep via actigraphy is a practical solution (Karlen et al., 2008). Actigraphy is a term to describe measuring movement by a microcomputer device worn by a person. This usually is a small device that is worn during sleep and typically can be worn on the wrist and looks like a standard wrist-watch. It can also be placed on the ankle or trunk. Actigraphs measure movements during sleep and use algorithms to calculate sleep patterns. Movements are usually used as an indication of wakefulness or restlessness. One limitation of actigraphy is that scoring is different between devices brands. The best validated measure of sleep using actigraphy is total sleep time and thus actigraphy is usually seen to be a measure of sleep duration rather than quality (Krystal & Edinger, 2008). One study validating actigraphy against PSG found no significant difference in sleep duration and movements; however, actigraphy is less accurate in patients with sleep disorders (Kushida et al., 2001).

Despite its popularity, actigraphy is known for inaccurately detecting small movements, such as sitting still resulting in a misclassifying of the state of wakefulness. The algorithm that includes cardio-respiratory data seems to have high accuracy in comparison to PSG and seems to be suitable wearing the devices everyday use (Karlen et al., 2008).

Perceived sleep scoring

Perceived sleep scoring using sleep diaries and sleep scales are often being used to monitor sleep duration and sleep quality. Experts in the field agree this to be a useful methodology (Carney et al., 2012). Sleep quality and refreshment after sleep can be indicated on a scale ranging from 1 to 10 where 10 indicates great sleep quality and ultimate refreshment after awakening (Knufinke, Nieuwenhuys, Geurts, Coenen, et al., 2018). Subjective sleep quality is important for analysing the perception of sleep in subjects (Myllymäki et al., 2011). Subjective sleep scoring has been shown not to differ significantly from PSG or actigraphy (Kushida et al., 2001).

There is a contrast in the literature as subjective sleep measurements on athletes have been found to be disassociated from objective sleep measurements. Self-reporting of good sleep quality has been accompanied by objective poor sleep quality markers (Krystal & Edinger, 2008). This was indicated in a study of 35 well-trained cyclists where wristwatch actigraphy during sleep was compared to a subjective sleep quality rating. Actigraphy showed sleep efficiency and total sleep time to decrease with higher training loads compared to the baseline and increased during the taper period. Subjective sleep quality was reported to increase irrespective of the increased in training load and kept on increasing during the taper period as well. A cited reason for this is that the athlete might be so exhausted that they assume they are sleeping better than they are. This is an indication that subjective sleep quality ratings must be used with caution when used on elite athletes (Teng et al., 2011).

Another study showed that self-reported measurements differ from objective measurements. This was indicated with the Pittsburgh Sleep Quality Index measurement not correlating with accelerometer recordings. The authors conclude that objective, as well as subjective measurements, are needed as a perception of the sleep quality has more clinical relevance to daytime functioning. Known limitations of wearable actigraphy devices for sleep monitoring such as the inability to differentiate between wakefulness and sleep while lying or sitting still and the inability to accurately record sleep onset emphasises the importance of also measuring sleep subjectively (Berger, Obeid, Timmons, & Dematteo, 2017). Self-perceived sleep estimates have been shown to overestimate total sleep time by 19.8 minutes compared to actigraphy in a group of professional rugby league players. A study on insomnia patients showed high intra-individual variability when estimating sleep with higher levels of pre-sleep cognitive activity and lower mood on awakening being the main factors for underestimating total sleep duration when sleep perception was compared to actigraphy over seven nights. Also, sleep onset latency was mostly overestimated when sleep effort was difficult. These results show inconsistency between subjective sleep monitoring compared to objective monitoring but more importantly, the effect mood state and psychophysiological variables have on the estimation of perceived sleep quality and perceived duration (Herbert, Pratt, Emsley, & Kyle, 2017).

Questionnaires

The two most widely used questionnaires in the field of measuring sleep abnormalities and chronotype are the Pittsburg Sleep Quality Index (PSQI) and the Horn-Östberg Morningness and Eveningness Questionnaire (MEQ). Both have been shown to be reliable measurements of subjective sleep measurement (Buysse et al., 2008; Grandner, Kripke, Yoon, & Youngstedt, 2006).

Pittsburgh Sleep Quality Index (PSQI)

This questionnaire gives a comprehensive view of the respondent's perceived sleep quality during the previous month (Krystal & Edinger, 2008). It contains 19 self-rated questions and the sum of the scores range between 0 and 21 with a higher value indicating poor sleep quality (Buysse et al., 2008) The cut-off point is at five where a score above this indicates poor sleep, however, a score of eight is also sometimes used as a more conservative cut-off point (Samuels, 2009).

Horn-Östberg Morningness and Eveningness Questionnaire (MEQ)

People peak at different times of the day due to individual circadian rhythms. This is known as chronotypes and is usually divided into “Morning types” and “Evening types”. The chronotype of a person can be determined by using a validated chronotype questionnaire such as the Horn-Östberg Morningness and Eveningness Questionnaire developed in 1976 (Horne & Östberg, 1976). Morning-type persons opposed to evening-type persons rise early in the day and prefer doing activities early in the morning. Extreme morning type people are called larks and evening type people owls (Waterhouse et al., 2012). This questionnaire consists of 19 questions and the sum of the scores is in a range of 16 and 86, with below 42 being an ‘evening type’ person and above 58 being a ‘morning type’ person. The score between 42 and 58 indicates that the subject is ‘neither type’.

2.8 Determining sleep quality

There does not seem to be a consensus in the literature for a definition of sleep quality (Harvey, Stinson, Whitaker, Moskovitz, & Virk, 2008; Krystal & Edinger, 2008). Sleep quality is poorly defined in the literature (Claudino et al., 2019). It is important to monitor the quality and quantity of sleep in athletes due to the known benefits of sleep on performance (Halson, 2014). Despite achieving the required total sleep duration, the quality thereof might be insufficient (Samuels, 2009). It is proposed that sleep quality should be related to tiredness on waking, feeling rested and restored during the day as well as the number of awakenings during the night (Harvey et al., 2008). Sleep quality may be a combination of sleep variables combined such as; total sleep time, sleep onset latency, fragmentation, total wake time, sleep efficiency and sleep disruptive events. PSG measurements, which include sleep architecture, such as sleep stages are also considered a potential influence on sleep quality. However, only week correlations exist between sleep diary entries and PSG ratings such as wake-after-sleep-onset (WASO), sleep onset latency (SOL) and total sleep time (TST) (Krystal & Edinger, 2008). The Pittsburgh Sleep Quality Index (PSQI) has been shown to have a poor relationship with polysomnographic and actigraphy recordings but cannot be used as a replacement for these (Buysse et al., 2008). It remains an open question if sleep quality can be determined from PSG measurements as Rosipal, Lewandowski, & Dorffner (2013) did not find any parameters that agreed with subjective sleep. However, the study found that total wake times during the night indicated poorer subjective sleep quality (Rosipal et al., 2013).

Lastly, the restorative outcome of sleep in athletes is likely to be dependent on four key factors: **sleep duration** (sleep length in total time), the **quality of sleep** (sleep disturbance / sleep efficiency / sleep fragmentation), **the phase** (circadian timing) of sleep (Fullagar, Duffield, et al., 2015; Samuels, 2009) and the **fitness** of the subject being tested (Shapiro et al., 1981). The quality of sleep, that is thought to ultimately determine the recuperative effect is dependent on sleep onset, fewer awakenings and less time spent awake during sleep (Driver & Taylor, 2000).

Uchida et al. (2012) suggest several different mechanisms on how exercise might enhance sleep quality. They explained that a meta-analysis of studies found shorter sleep onset latency, shorter time awake after sleep onset and longer total sleep time after exercise. They concluded that because exercise has been shown to improve mood, there might be a mechanism in which a positive mood relates to better sleep quality which shows and influence on each other.

Acute and chronic bouts of exercise might also affect sleep. Experimentation studies showed acute and chronic exercise only to have a modest effect on sleep whereas epidemiological studies showed exercise to have a bigger improvement in sleep (Youngstedt & Kline, 2006). One reason for these findings may be due to the research being done in an unnatural environment where the research participants slept in a laboratory. Other reasons might be that mostly good sleepers were tested and limited sample participants were used. Reviewing the literature, Youngstedt et al. (2006) noted that people perceived exercise as one of the most important factors to improve sleep.

Sleep efficiency

A very recent 2019 meta-analysis reviewed numerous ways to determine sleep quality in team sports athletes. The authors made recommendations on measuring sleep quality, based on 35 studies from a literature search meeting strict criteria. The combined number of participants in these studies reviewed was 4083. They were from various team sports from 27 countries. Thirty measuring instruments were investigated from which sleep scales and questionnaires made up the bulk of the measurements with actigraphy being the single most used instrument by researchers, possibly because of the ease of use and high reliability and validity reported. Sleep diaries were also particularly helpful in tracking athletes sleep. It was found that when using actigraphy sleep quality is best determined using sleep efficiency as a measure. Sleep efficiency is not standardised in the literature and numerous calculations are used to determine this. Even though there is not a good correlation between subjective and objective sleep reports, subjective reports may be valuable to provide a unique insight into the sleep of the athlete. It was again concluded that even though PSG is regarded as the gold standard of sleep monitoring, this is highly impractical and too expensive to be used regularly by elite athletes (Claudino et al., 2019).

Sleep latency

Sleep latency is important in determining sleep quality and is defined as the time between lying in bed ready to sleep after lights out to the first occurrence of stage 1 sleep. The shortest sleep latency was noted at the lowest point of the core body temperature rhythm (Dijk & Czeisler, 1995).

Sleep duration

It seems that sleep duration might be the most important contributor to sleep quality and alertness. Sleep duration has been shown to be one of the most crucial aspects of sleep for next-day performance and alertness (Gillberg & Åkerstedt, 1994).

Sleep fragmentation

Sleep fragmentation refers to waking during sleep and is also called “sleep continuity”. These arousals disrupt sleep and are believed to diminish sleep quality and interfere with the recuperative process independent of sleep duration. Sleep fragmentation can be as a result of external stimuli such as noise, or internal stimuli such as apnoea. There is no clear evidence that stage 1 sleep has any beneficial impact and it seems if this is a “neutral” stage that only serves as the transition stage between sleep and wakefulness. It is likely that once this stage is entered the recuperative effect of sleep does not take place yet, but the harmful effects of wakefulness have stopped. Although sleep continuity is essential for optimal daily functioning (Bonnet, 1985), there seems to be not enough evidence to support the hypothesis that sleep fragmentation has an additional negative impact on recuperation (Wesensten et al., 1999).

2.9 External influencing factors on sleep

There are also other external factors that might impact sleep quality and quantity that cannot necessarily be controlled. These are described below.

Sleep loss and pain tolerance

A few studies reported decreased pain tolerance after sleep deprivation. Sleep restriction of only a few hours has a decreasing effect on pain tolerance. The extent of this seems to correlate with the amount of sleep loss (Roehrs, Hyde, Blaisdell, Greenwald, & Roth, 2006). Similar results were found with the participants in a sleep restriction group having significantly higher pain ratings than the control group (Simpson, Scott-Sutherland, Gautam, Sethna, & Haack, 2018).

Jet lag

Jet lag is a term describing the desynchronization of the internal body clock to the environment (Facer-Childs & Brandstaetter, 2015). In athletes, travelling for competitions across time zones can disrupt circadian rhythms. This seems to be worse when travelling in an eastward direction compared to westwards (Fullagar et al., 2016). Jet lag has mental and performance consequences that can affect an athlete's performance (Kruyt & Grobbelaar, 2019). These effects may last until the athlete has adjusted to the local time zone (Manfredini et al., 1998).

Caffeine

Caffeine is a known stimulant that can raise alertness and decrease sleep pressure. This can have the desired effect on performance, but this effect is unwanted if sleep needs to commence. It has been shown that caffeine (400 mg) might still disrupt sleep even if the caffeine was taken six hours prior to bedtime (Drake et al., 2013).

Artificial bright light exposure

Studying the effects of light-emitting diodes (LED)-backlit of a computer it was found that spending time in front of this screen in the evening has disrupted consequences for sleep. Short-wavelength light in the blue range (460 nm) is known to be capable of resetting the circadian pacemaker. A result of this bright artificial light is a circadian phase delay as the suprachiasmatic nuclei receive a prolonged light signal thereby suppressing melatonin production in the evening and increasing alertness (Cajochen et al., 2011). Playing computer games before bed increased sleep latency, decreased subjective sleepiness and decreased REM sleep (Münch et al., 2006). However, this is not always supported in the literature. One study could not find any difference in sleep quality, quantity or next-day performance after a group of highly trained netball players were exposed to two hours of bright light before bed (M. J. Jones et al., 2018). Another study showed no significant difference between bright light displays and dark light displays used, except that a bright light display reduced subjective sleep quality (Higuchi, Motohashi, Liu, & Maeda, 2005). A study in athletes showed the opposite than was expected when a shorted sleep onset latency with exposure to blue light was found (Knufinke, Nieuwenhuys, Geurts, Coenen, et al., 2018).

Sleep Hygiene

At least one study found a moderate to a strong correlation between sleep hygiene and poor sleep quality. Sleep hygiene is not limited to bedtime routine, but include bright blue light exposure before bed, caffeine, alcohol and large meal consumption before bedtime (Knufinke, Nieuwenhuys, Geurts, Coenen, et al., 2018).

This concludes the first section of the literature review. The importance of sleep for optimal function in everyday life cannot be underestimated. As was seen in this part of the chapter, sleep deprivation has adverse health and cognitive consequences. Optimum sleep duration in the normal population has been investigated and reported on. The next section explores sleep in athletes especially in team sports and elite athletes.

SECTION B: Exercise and Sleep

2.9 Training load and its components

Physical exercise should place enough stress on the body to evoke a stimulus triggering physiological responses in the biological systems of the body (Cardinale & Varley, 2017). This has been called a "dose-response" relationship where the dose is the training stress and the response is the adaption of the body to this stress resulting in an altered performance (Lambert & Borresen, 2010). Exercise cause disturbance in the homeostasis control of the physiological systems in the body which is rectified during recovery. This will result in a subsequent training stimulus of similar intensity to cause less homeostatic disturbance in the body, adapting the athlete to the training load (Borresen & Lambert, 2009). Even though high training volumes are necessary for success this might also have adverse outcomes such as overtraining if not managed correctly (Foster, 1998).

To understand the impact that training and competition have on an athlete, training load must be measured as this gives valuable information to the trainer and the athlete. This is significant in order to modify training programmes to optimize the athlete's training and recovery as well as to establish if an athlete is adapting to a training programme. Even though it is known that an increase in training will improve performance this might also have the opposite effect and may lead to injury, non-functional overreaching and ultimately overtraining if training load is spiked erratically. The training effect is determined by the frequency, duration and intensity of exercise (Borresen & Lambert, 2009). Training load can be measured internally or externally and dissociation of these two might be an indication of undesirable training effects (Halson, 2014). There are various different ways of measuring training loads such as using global positioning systems (GPS), heart rate and blood lactate measurements and force plates (Bourdon et al., 2017). Physiological stressors from training can be measured internally using various measures such as blood lactate, VO_2 and rating of perceived exertion (RPE). This is called internal load. External load are objective measures such as power output and GPS measurements. Internal and external training load indicate the impact of physical exercise on the athlete's body.

One way of quantifying training load can be by using volume and intensity. Volume may refer to the duration of the exercise session in minutes or hours, but may also be other variables such as distance covered. Exercise intensity, on the other hand, refers to how hard a training session was and can be measured in heart rate, oxygen consumption or the athlete's perceived exertion. Training load can be calculated by multiplying exercise volume with exercise intensity to measure the stress imposed on athletes.

Perception of Effort (RPE)

RPE was created to gauge the perceived stress experienced while performing physical activity measured (Borg, 1982). In the 1960's Gunner Borg invented the Borg RPE Scale where a person can use a number between 6 and 20 to indicate physical stress experience while performing an activity. Due to heart rate following a linear increase with the increased workload the chosen number represents a heart rate between 60 and 200. This was later modified by Borg himself called the Category Ratio Scale where a number between 1 and 10 can be selected. This was done to make interpretation easier for participants. For example, a selection of 2 on this scale indicates that the physical activity was very light, opposed to 10 which is very, very hard (Borg, 1982). This is still the most frequently used scale to asses internal load. Other than being easy to understand, this method (RPE), is cost-effective, non-invasive and easy to measure in order to asses an athlete's internal load (Cardinale & Varley, 2017). Foster adapted Borg's Category scale by asking the athlete to give a global rating of the exercise session between 10 minutes and 30 minutes after the conclusion of each session. This was called the session RPE method (Foster, 1998). Athletes can gauge their internal effort and stress during exercise in order to provide a subjective score of their perception of effort afterwards (Borresen & Lambert, 2009). The session RPE method has been shown to be a valid method of quantitating exercise training (Foster et al., 2001). This was shown when comparing the session RPE method against an objective heart rate method in two different sport types (Foster et al., 2001). Another study showed Session RPE correlated well to $\%VO_{2peak}$ ($R^2 = 0.76$), $\%HR_{peak}$ ($R^2 = 0.74$) and $\%HR_{reserve}$ ($R^2 = 0.71$) (Herman et al., 2006). Studies showed weak correlations when other methods of training load monitoring were compared to RPE.

Even though RPE was shown to be a valid method of assessing the stress exercise placed on an athlete during exercise, literature has also shown that it might not always be reliable (Halson, 2014; Lambert & Borresen, 2010). A meta-analysis of the validity coefficients between Borg's RPE scale and other physiological measurements were lower than was conventionally believed (Chen, Fan, & Moe, 2002). Using questionnaires to report exercise intensity, athletes may over- or underestimate the activity they are doing and have to rely on memory to complete the questionnaire. RPE is still a valuable subjective measurement of an athlete's perception of exercise intensity (Borresen & Lambert, 2009).

Session RPE (sRPE) was later developed by Carl Foster to measure an athlete's perceived exertion for and exercise session (Foster, 1998; Foster et al., 2001). The session RPE score (load) of the exercise session was calculated by multiplying the RPE (on a 1 – 10 scale) during an exercise session with the duration of the exercise session: $Session\ RPE\ score = \ session\ RPE\ \times session\ DURATION.$ Multiple training sessions on a day were termed daily training load and is calculated by the summation of all the session training load scores for the particular day: $Daily\ Training\ Load = \sum(sRPE\ \times\ sDuration\ for\ the\ day.$ This method has been shown to correlate very well (between r = 0.75 and r = 0.90) with the sum of heart rate zone scores ($\sum HR\ \ Score$) (Foster, 1998). Training load using the Session RPE method has been shown to be a valid and reliable way of quantifying the impact of exercise in various sports (Coutts, Wallace, & Slattery, 2004).

A spike in workload has been associated with an increase in injury risk (Murray, Gabbett, Townshend, & Blanch, 2016). An acute to chronic workload ratio (ACWR) is determined by calculating the ratio between the rolling average workload for a certain period (usually four months) and the current period's workload (usually a week). For instance, the average workload for four weeks of a month can be compared to the current week's workload. Manging the ACWR between certain ranges decreases the risk of injury (Bourdon et al., 2017). This ratio should approximately not be less than 0.8 and should not exceed 1.5 (Gabbett, 2016). Illness correlates with a spike in training load and suppression of the immune system is given as a reason for this effect (Foster, 1998).

Team sport athletes are often considered more difficult to monitor than individual sport athletes, because of the diverse range of activities as well as the 'cognitive load' such as the training of skills that is important in many team sports. It is important to note that athletes respond differently to training load (Halson, 2014).

In professional rugby league players, it was found that external training load varies on how it relates to sleep. The greatest effect was seen when acceleration and deceleration demands were increased, showing an increase in sleep efficiency and duration (Thornton, Delaney, Duthie, & Dascombe, 2018).

From the above literature research it is evident that sleep is a broad topic with many complex relationships. It was highlighted that sleep is vital in athletes to optimise performance. Next, a closer look is taken on how exercise affects sleep.

2.10 Exercise and Sleep in the literature

Although sleep and exercise are governed by different physiological mechanisms, more studies are showing a relationship between these two behaviours (Atkinson & Davenne, 2007; Davenne, 2009). It has been suggested that sleep and exercise exerts a reciprocal positive effect on each other through multiple physiological and psychological pathways (Chennaoui et al., 2015; Dolezal, Neufeld, Boland, Martin, & Cooper, 2017; Youngstedt & Kline, 2006). It is vital to consider this bidirectional relationship when studying sleep and exercise (Dolezal et al., 2017; Kline, 2015). Optimal sleep is required in athletes for high levels of mental and physical performance, recovery and prevention of exercise-induced diseases (Chennaoui et al., 2015; Venter, 2012). Exercise may have an effect on the central nervous system, alter body temperature, affect cardiac and autonomic function, endocrine and metabolic function. These may all have an effect on subsequent sleep (Uchida et al., 2012). Exercise seems to be vital for general well-being, but exercise may also stress the body affecting sleep (Driver & Taylor, 2000; Shapiro et al., 1981). For elite athletes, the burden of excessive competition, travel and training may all play a role in deteriorating sleep quality and duration (Gupta et al., 2017). It has been shown that in elite rugby players, sleep before and after competition is poor, even worse than the non-athletic population (Shearer et al., 2015). This contributes to poor recovery.

The benefit of optimal sleep is often overlooked as adults are poor in assessing the impact of sleep loss and elite athletes prioritise sleep lower than other recovery modalities (Simpson et al., 2017). There are numerous physiological benefits of sleep after exercise, but recent studies showed sleep after evening competition may reduce total sleep time by as much as 1h40min and increase sleep latency by 45 minutes (Donnell et al., 2018). Poor sleep may hinder recovery after a match and a continuation of a lack of sleep add to the stress that is already imposed by exercise (Nédélec et al., 2015). It is likely that because of frequent high-intensity training and competition athletes need more sleep than non-athletes to ensure adequate recovery from training (Lastella, Roach, Halson, & Sargent, 2015).

Elite athletes are often exposed to other factors that disrupt subsequent sleep such as jet lag or anxiety (Souissi et al., 2003). Chronodistruption due to late-night training or matches, exposure to bright light, consumption of caffeine and/or alcohol and travel were all cited as possible reasons for sleep disruptions athletes might experience (Nédélec et al., 2015). In addition to earlier morning training times, increased training load, travel times as well as altitude, all negatively affect sleep in athletes when they need it (Roberts et al., 2019).

Table 2.1 Conflicting results of previous research investigating the effect of training duration, intensity and load on sleep duration and quality

Authors	Year	Study	Population	Subjects	Exercise Code	Sleep Duration	Sleep Quality
Increased Exercise Duration							
Youngstedt et al.	1997	Review	Athletic	Studies: 38 n=401	Not Specified	↑	⇔
Myllymäki et al.	2012	Original	Athletic	n=14	Individual	⇔	⇔
Driver & Taylor	2000	Review	Athletic	Not Specified	Not Specified	↓	↓
Shapiro et al.	1981	Original	Athletic	n=6	Individual	↑	↓
Kjeldsen et al.	2012	Original	Non-Athletic	n=32	Individual	↑	↑
Increased Exercise Intensity							
Horne & Staff	1983	Original	Athletic	n=8	Individual	↓	↑
Myllymäki et al.	2012	Original	Athletic	n=14	Individual	⇔	⇔
Driver & Taylor	2000	Review	Athletic	Not Specified	Not Specified	↓	↓
Robey et al.	2013	Original	Athletic	n=12	Team	⇔	⇔
Gupta et al.	2017	Review	Athletic	Not Specified	Team & Individual	⇔	↓
Marshall & Turner	2016	Review	Athletic	Not Specified	Team & Individual	Not Measured	↓
Shearer et al.	2015	Original	Athletic	n=28	Team	↓	↓
Miller et al.	2017	Original	Athletic	n=51	Team	⇔	↓
O'Donnell et al.	2018	Original	Athletic	n=10	Team	↓	↓
Brand et al.	2014	Original	Non-Athletic	n=52	Individual	↑	↑
Increased Exercise Load							
Baekeland & Lasky	1966	Original	Athletic	n=10	Team & Individual	Not Measured	↓
Lira et al.	2011	Original	Non-Athletic	n=14	Individual	⇔	↑
Youngstedt & Kline	2006	Review	Athletic	Not Specified	Not Specified	Not Measured	↑
Dolezal et al.	2017	Review	Non-Athletic	Studies: 34	Individual	Not Measured	↑
Baron et al.	2013	Original	Non-Athletic	n=11	Individual	↑	↑
Banno et al.	2018	Review	Non-Athletic	Studies: 9 n=557	Individual	⇔	↑
Buguet et al.	1998	Review	Athletic	Not Specified	Individual	Not Measured	↓
Fullagar et al.	2015	Review	Athletic	Not Specified	Team sport	↓	↓
Leduc et al.	2019	Original	Athletic	n=9	Team	↓	↓
Killer et al.	2015	Original	Athletic	n=13	Individual	↑	↓
Thornton	2016	Original	Athletic	n=31	Team	↓	↓
Knufinke et al.	2018	Original	Athletic	n=98	Team & Individual	⇔	↓
King et al.	2008	Original	Non-Athletic	n=66	Individual	⇔	↑
Pitchford et al.	2017	Original	Athletic	n=19	Team	↓	↓

Teng et al.	2011	Original	Athletic	n=28	Individual	↓	↓
Hausswirth et al.	2014	Original	Athletic	n=27	Individual	↓	↓
Stuart et al.	2019	Review	Athletic	n=54	Team & Individual	↓	↓
Kölling et al.	2016	Original	Athletic	n=55	Team	↓	↓
Kredlow	2015	Review	Non-Athletic	Studies: 66	Individual	↑	↑

Table 2.1 Conflicting results of previous research investigating the effect of training duration, intensity and load on sleep duration and quality (cont.)

↑ = Increase; ↓ = Decrease; ⇔ = No Change

2.11 The effects of exercise on sleep

The effect of exercise on sleep has been long debated in English literature (Buguet, Cespuglio, & Radomski, 1998; Driver & Taylor, 2000). Exercise and sleep are a complex set of activities. Sleep-promoting effects of exercise are difficult to answer as exercise may be physiologically and psychologically beneficial, but may also stress the body (Driver & Taylor, 2000).

There is currently no reference values for sleep duration and quality of elite athletes. Neither has the impact of daily variation in training load on the sleep quality and quantity of elite athletes been studied to provide univocal evidence of the impact thereof (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). Gupta et al. (2017) identified training, travel and competition to be the biggest risk factors for sleep disturbance on elite athletes. It is evident that regardless of studies into physical exercise and sleep, this relationship lacks understanding (Killer et al., 2017; Uchida et al., 2012). It is proposed that sleep poses a restorative effect after exercise and this may cause alteration in sleep parameters (Shapiro et al., 1981).

Baekeland and Lasky (1966) were the first to show exercise to have an effect on subsequent sleep. Studies on the elderly and non-athletic population consistently showed exercise to improve sleep, but mostly when intensity was moderate and the duration of the exercise session was not excessive, however, it should be noted that these effects took long to manifest (King et al., 2008; Kjeldsen et al., 2012; Kline, 2015; Lira et al., 2011; Youngstedt & Kline, 2006). Numerous studies have found exercise to be a good remedy for sleep disturbances (Banno, Harada, Taniguchi, & Tobita, 2018; Dolezal et al., 2017). Exercise has even been suggested to be administered as a natural non-pharmacological intervention to sleep problems without undesirable side effects as the effects of non-pharmacological treatment is slower, but more durable (Banno et al., 2018; Kjeldsen et al., 2012). It should be noted that exercise might be more effective for people with severe or chronic sleep disturbance (Kline, 2015).

Although epidemiological studies have consistently found a relation between better self-reported sleep and exercise (Youngstedt & Kline, 2006), this is often in contrast to experimental studies which mostly only found small to moderate positive effects on sleep after exercise (Driver & Taylor, 2000; Kredlow, Capozzoli, Heron, Calkins, & Otto, 2015). Some studies could not find any change in sleep following exercise

(Myllymäki et al., 2012; Robey et al., 2014) and other studies showed exercise to be disruptive to sleep should the exercise be too exhaustive (Gupta et al., 2017; Killer et al., 2015; Shapiro et al., 1981).

Reasons for exercise affecting sleep

Suggested reasons for alterations in sleep after evening exercise was a change in core temperature resulting in a thermo-physiological disturbance. Due to exercise's effect on body temperature, it might influence sleep quality as it has been shown that a decrease in body temperature promotes sleep, but an elevated body temperature delays sleep onset (Chennaoui et al., 2015). The authors of this study advised that future research must look at exercise on sleep quantity. This poses the question if it is possible that sleep problems might be related to inadequate temperature downregulation?

Also, the delay of parasympathetic activity following exercise caused a higher heart rate at bed-time (Nédélec et al., 2015). Furthermore, waking and sleeping are affected by exercise as serotonin and/or serotonin/dopamine ratio promotes wakefulness after exercise. On the other hand, after a long duration of exercise, central fatigue forces the body to rest which promote sleep (Davenne, 2009).

It has been hypothesised that when exercise load is too high for an individual's capabilities, the hypothalamo-pituitary-adrenocortical axis (HPA) is activated in a somatic stress response which leads to a decrease in total sleep duration, Slow-wave-sleep (SWS) and REM. Moderate exercise evokes moderate HPA activation called neurogenic stress, which in return may enhance SWS and REM. Thus, when the central mechanism is exposed to somatic stress, sleep structure disruption is evident, but neurogenic stress may increase SWS and (or) REM which is likely to be the brain's coping mechanism (Buguet et al., 1998).

Cytokines, especially interleukin-1 (IL-1), interleukin-6 (IL-6) and tumor necrosis factor (TNF) have been associated with regulating sleep after exercise. The stress response of exercise induces an increase in pro-inflammatory cytokine levels. Pro-inflammatory cytokines after exercise have been identified to influence sleep. In relation to exercise, plasma concentrations peak during sleep, but IL-6 can increase more than 100 times after exhaustive exercise. Moderate exercise has been shown to have a positive effect on sleep with exhaustive exercise showing the opposite effect. This might be explained by the release of the pro-inflammatory cytokines after exercise as IL-6 released in low concentrations may promote drowsiness. Higher exercise loads increase the IL-6 release and this high concentration promote wakefulness either via direct action of these cytokines on sleep or indirectly on HPA activation. This increase body temperature, decrease non-REM and increase wakefulness (Santos, Tufik, & De Mello, 2007).

2.12 Training load and Sleep

a) Training load and sleep quality and quantity

There is evidence for more sleep disturbances with higher training volumes in team sports (Fullagar, Duffield, et al., 2015). Only one study focused directly on the effect of training on sleep quality and quantity in Rugby Sevens players. This was also the first published study to objectively monitor sleep in elite Rugby Sevens players. Nine international male Rugby Sevens players were monitored during pre-season using actigraphy and subjective sleep measurements. Sleep measurements from the week with the highest training load were compared to the week with the lowest training load. Results showed sleep quality and quantity to be impaired during the highest training load week. There was also a small decrease in total sleep time, fragmentation index and subjective sleep quality between the highest and the lowest sRPE weeks. This study evidently shows training load's effect on sleep quality and quantity in Rugby Sevens players (Leduc et al., 2019).

Although the literature is contradicting, training load has been shown to negatively impact sleep quality and sleep duration. There is evidence that if a threshold of >25% increase in training load is surpassed, total sleep time seems to be negatively affected (Roberts et al., 2019). Using wristwatch actigraphy to monitor 30 elite male cyclists, sleep duration and sleep quality were significantly reduced when training volume and intensity were increased for three weeks. This effect was reversed following a two-week taper period after the intensified training period. Sleep fragmentation also increased during this intensified training and decreased with the taper period. Interestingly, the participants' subjective sleep scores increased with the increased workload and kept on increasing during the taper period (Teng et al., 2011). Another study showed similar results of a decline in sleep quality in well-trained cyclist after nine days of intensified training. This included a decreased sleep efficiency, more wake bouts as well as more fragmented sleep after weekly training volume was increased by 153% and intensity was increased by 146% (Killer et al., 2017). Similar results were reported for functional-overreached (F-OR) triathletes. Using wristwatch actigraphy, sleep duration and sleep quality decreased during the overload phase of a training programme. Compared to the control group these triathletes that were categorised as F-OR had a 7.9% decrease in sleep duration, a 1.6% decrease in sleep efficiency with a 0.7% decrease in immobility time. Functional-overreached athletes also experienced more illness than the control group (Hausswirth et al., 2014). When training load during a two-week training camp was increased through longer exercise session duration and higher intensities, sleep quality and quantity were decreased. Using wristwatch actigraphy to measure sleep in professional rugby league players, total sleep time, time in bed and sleep efficiency all decreased by 85 minutes, 53 minutes and 8% respectively. Taking naps during the day seemed to offset some of these negative effects, showing the beneficial effect of napping when athletes are exposed to high training volumes (Thornton et al., 2016). Investigating training load on highly trained junior rowers at a training camp, showed a decrease in sleep duration during the periods of high training load (Kölling, Steinacker, Endler, Ferrauti, & Kellmann, 2016).

In contrast to this, no other studies found a relationship between training load and sleep. No correlation between daily variation in training load and total sleep time were found when elite Australian Rules football players were monitored at home. However, when they were on a training camp higher training loads were associated with a reduction in total sleep time, where as lower training loads were showed to have the opposite effect (Pitchford et al., 2017). A study investigating the effect of day-to-day variation of perceived training load on sleep on 98 elite athletes, could not find any conclusive evidence that sleep quality or sleep stage distribution was altered

(Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). There are studies showing moderate aerobic exercise enhance sleep quality of elderly men. However, this was only visible after six months after the training started (Lira et al., 2011).

There are physiological theories for the disruption of sleep after exercise. Workload is directly proportional to body temperature (Driver & Taylor, 2000). Changes in core temperature could disrupt the thermo-physiological pathway responsible for sleep onset (Nédélec et al., 2015). Decreasing body temperature through dissipation of heat mechanism via peripheral vasodilation might be essential for initiating sleep and this gradient between distal and proximal skin temperature seems to be the main factors for sleep onset (Chennaoui et al., 2015). Disruptions to body temperature such as increased training load may affect this pathway affecting sleep onset. Another supporting theory for body temperature changes to initiate sleep is that these temperature changes trigger somnogenic brain areas (Atkinson & Davenne, 2007). Notwithstanding this evidence, the thermo-hypothesis of exercise's heat-inducing effects as the main reason for effecting sleep is still debated as other studies showed body temperature to return to normal 1.5 – 2.0 hours after the exercise was terminated with rectal temperature returning to normal after five to six hours (Buguet et al., 1998). The influence of exercise's heat-inducing effect on body temperature to alter sleep was also questioned by Kredlow et al., (2015) who also found beneficial effects of exercise on sleep regardless of the time of day the exercise was performed.

In addition to the thermoregulatory theory, there is another physiological explanation for how exercise might affect sleep duration as reported in this study. The effect of exercise is regulated by the limbic-sensitive pathway and the capacity for the brain to deal with the stress induced by exercise. With moderate exercise, the hypothalamo-pituitary-adrenocortical axis (HPA) is bypassed or only slightly activated which leads to an increase in sleep duration. Should the exercise load be too great or the subject not conditioned sufficiently to handle the exercise load, circulating cortisol and sympathetic activity is increased which downregulate the human stress system, the (HPA) is overloaded and strongly activated which results in sleep duration to be decreased (Buguet et al., 1998).

The effect of fluctuations in training load on sleep in athletes is a key focus area in team sports. Further investigation in future studies is needed for a better understanding between acute training load and sleep. This may be helpful in prescribing training plans, improving performance and avoiding overtraining (Watson, 2017).

b) Exercise duration and sleep quality and quantity

Exercise duration has been shown to alter sleep in athletes (Driver & Taylor, 2000). This support the restoration theory which proposed an increasing need for sleep after increased physical exhaustion. When looking at training duration during a training camp of rugby league players, there seems to be a trivial negative relationship with sleep duration (Thornton et al., 2016). However, experimental studies have found exercise's effect on sleep to be small to moderate, but, long-duration exercise may disrupt sleep significantly. This was shown by examining the sleeping patterns of six athletes for four consecutive nights after a 92 km ultramarathon. Sleep duration significantly increased from the control night's sleep and for three nights after the race. Sleep duration was the longest on the second night after the ultramarathon. This might be evident for the requirement of extended sleep for recovery after an excessive amount of exercise (Shapiro et al., 1981). A study of professional rugby league players also found a relationship between increased training duration above the individual's baseline and a decrease in total sleep time (Thornton et al., 2016).

Myllymäki et al. (2012) could not find any change in sleep duration after acute exercise duration was increased. Even after 90 minutes at 60% of VO_{2Max} there was no change in sleep duration, and it was concluded that the threshold of sleep disturbance might not have been reached yet. They noted that sleep duration seems to be greater when exercise duration was longer than one hour (Myllymäki et al., 2012), Driver & Taylor (2000) set this threshold at over two hours (Driver & Taylor, 2000). Youngsteadt et al. (1997) concluded that because a relative fit population was studied, a longer exercise duration is needed to elicit a sleep response. It should be noted that sleep duration was found to be longer after training when sleep was administered ad libitum (Youngstedt, Connor, & Dishman, 1997).

It should be noted that most studies in the literature included "good sleepers" which creates a "ceiling-effect" leaving little room for improvement. A meta-analysis study showed an increase in total sleep time (TST) after exercise (Driver & Taylor, 2000). In a meta-analytic review of 38 studies on the effect of acute exercise on sleep, the authors could only find moderate effects of exercise on total sleep time. Total sleep time increased if exercise was conducted for more than an hour. It is important to note that the duration of exercise seemed to be the most reliant for changes in sleep architecture (Youngstedt & Kline, 2006).

Excessive training demands have been shown to disrupt the quality of sleep. This was shown after an ultra-marathon where subjective sleep quality was reported to be lowest after the first night of the race with the highest being after the second night of sleep after the race. Wakefulness during sleep was experienced most on the first night after the ultra-marathon and can possibly be explained by muscle soreness and blister pains. This disrupted sleep might be the reason for the longest sleep duration on the second night after the race (Shapiro et al., 1981). A significant decrease in sleep quality was found when training intensity of 13 highly trained cyclists was increased by 143% for nine days. (Killer et al., 2017). In contrast to this, no change in sleep quality was found by Myllymäki et al. (2012) even at the longest exercise duration of 90 minutes at 60% VO_{2Max} (Myllymäki et al., 2012).

c) Exercise intensity and sleep quality and quantity

Sleep duration seems to be affected by extreme exercise intensities. A review study highlighted that 28% of elite athletes experience sleep disturbances during periods of heavy training. It has also been reported in the same study that some athletes might even experience symptoms of insomnia during these periods (Gupta et al., 2017). Sleep duration, as well as sleep efficiency, was significantly reduced after competition when compared to a training session of similar intensity and a rest day in 10 elite female netball players. Cortisol levels were measured and showed significantly higher values after matches compared to training and control sessions. This might be an indication of the combination of high-intensity competition and the psychological stress athletes are exposed to during competition. This must be taken into account when recovery is planned (O'Donnell, Bird, Jacobson, & Driller, 2018). Sleep duration was not altered in a study of 98 elite athletes during 10 days of regular training intensity. The authors suggested that the training intensity (an RPE score of 5.4 ± (2.5)) may not have been high enough to elicit an altered sleep response (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). Supporting this, other studies as well could not find changes in sleep quality when studying the effect of exercise intensity on sleep quality. Using wristwatch actigraphy to measure sleep quality, subjects had to perform five exercise sessions at home. Subjects ran at 45% (easy), 60% (moderate) and 75% (vigorous) of their maximal oxygen uptake for 30 minutes at each intensity. None of these intensities elicited any changes in sleep quality (Myllymäki et al., 2012). However, heart rate during the subsequent night was affected (Myllymäki et al., 2012). Similarly, another study found no difference in sleep duration with exercising at high intensity for short durations. It was concluded that the change in body heat accompanied by a greater fall in body temperature might be responsible for sleep and not exercise itself as experiments heating the body gave the same results as exercise (Horne & Staff, 1983). Also in soccer players, using sleep scores as well as actigraphy did not find any difference in sleep duration after high-intensity exercise (Robey et al., 2014). Furthermore, intense exercise has been shown to decrease sleep quality. In a survey of 283 Australian athletes, 52.5% reported sleep disturbances after a late-night event while 27.7% reported sleep disturbances after heavy training sessions (Juliff et al., 2015).

Contrary to this, no disturbance in sleep quality could be found after vigorous late-night exercise compared to a control day among 11 fit athletes. No difference in sleep actigraphy nor subjective sleep quality could be found. This is interesting as the exercises ended on average only two hours and 13 minutes before bedtime (Myllymäki et al., 2011). Similarly, no changes in sleep quality nor sleep stage distribution when monitoring 98 elite athletes over a seven-day period with varying perceived training load were found. High training intensities did not alter sleep onset latencies or wake after sleep onset. Reasons for this might be that on a scale of 1 – 10 (where one is the lowest and 10 the highest perceived intensity) the average training load was 5.4 ± (2.5) which was not extremely high, and all exercise was completed more than three hours before bedtime. The "ceiling effect" might explain why deep sleep did not increase as the upper limit was already reached in elite athletes (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). Furthermore, higher self-perceived exercise exertion before bedtime failed to show any sleep disruptions when objectively monitored using PSG measurements (Brand et al., 2014).

It was found that compared to rugby union and soccer, Australian Rules football players have the lowest sleep quality. Even though there was no difference in the sleep duration between the three sports, Australian Rules football players spend the most time in bed, took longer to fall asleep, spend more minutes awake during a sleep period and recorded higher amounts of movement. This might be attributed to the high volume of distance covered (more than rugby union, but less than soccer) and the number of collisions between players (less than rugby union, but more than soccer). It is hypothesised that this high training and competition volume, as well as collisions, increase wakefulness due to an increase in pro-inflammatory cytokines causing a rise in body temperature and cortisol secretion (Miller et al., 2017).

A review study by Driver and Taylor (2000) eluded that measurements of improved sleep quality should display shorter sleep onset, fewer awakenings and less time awake. The same authors mentioned that it is possible that exercise may be beneficial in promoting sleep, but the opposite might also be true, in that there seems to be a threshold where strenuous exercise disrupts sleep. They concluded that based on the available studies, it is likely that exercise may have a positive effect on sleep at moderate endurance intensities, but not at exhaustive high-intensities and excessive long-durations. Even though body temperature increases proportional to workload, there is little evidence that the thermogenic effect of exercise has any effect on sleep quality or architecture (Driver & Taylor, 2000).

Sleep and exercise influence each other in a reciprocal manner although it might also be reliant on other factors such as age, fitness level and duration and intensity of exercise.

SECTION C: RUGBY SEVENS

Rugby Sevens is a popular form of Rugby Union. With Rugby Sevens being included in the Summer Olympic Games it has drawn more interest from all over the world

(Williams et al., 2018). Rugby Sevens are played on the same pitch dimension as the Rugby Union 15-man code with similar laws, but with only seven players in a team and five substitution players. Matches are 14 minutes in duration, made up of two halves of seven minutes, however, matches some times last longer as overtime is allowed. Similar to Rugby Union there are two ways of scoring points in the game. The scoring system is the same as the 15-man code, where a try counts five points, a conversion two points and a penalty kick or drop goal counts three points. A try is scored when a player of a team place the ball behind the opposition's try-line and then also have the opportunity to add two more points by kicking a drop-kick called "conversion" where the player is attempting to kick the ball over the crossbar and between the two upright posts of the opposite team. When a team, have a penalty kick, which is awarded after a penalty is conceded by the opposite team they may "kick for goal" and have the opportunity kick the ball between the upright posts and over the crossbar of the opposite team. A drop-goal may be taken at any time in the game during general play where the player attempts to kick the ball over the crossbar, by dropping the ball first on the ground and kicks it on the upwards bounce. In order for the defending team to avoid the opposing team from scoring a try, the defending team must tackle the player with the ball in an attempt to stop the attacking player from advancing or to try and gain possession of the ball. Players may only pass the ball backwards, and a pass forward or dropping the ball forward will result in a scrum with the opposing team throwing the ball into the scrum. A scrum is formed by three players from each team binding with each other. Each team's players that are bound, try and push the other team's players away from the ball which is being "fed" into the scum by one team's player.

When the ball is outside the playing area, a lineout is formed with three players of each team lining-up against each other at the place the ball went out of play. The team that did not put the ball out of play throws the ball into the lineout, and the teams contest the catching of the ball by jumping in order to gain possession.

Rugby Sevens has been shown to be a high-intensity sport with high intensity running demands and physical collisions with short periods of recovery. Players are exposed to heart rates of >80% of maximum heart rate for more than 75% of the game time. In total players cover on average around 1.5 km during a match ranging from 1.3 km to 1.9 km. Work to rest ratios is 1:0.5 (0.5 minutes rest for every 1 minute of work). Maximum speeds of 29.9 km/h were recorded (Suarez-Arrones et al., 2012). Compared to Rugby Union players spend more time in the high intensity running zones (>5m/s). To adapt to the demands of the game there is a difference in the physical characteristics of the players and their playing position compared to Rugby Union. The backs compared to the forwards are lighter, shorter and possess a lean body composition (Ross et al., 2014). These demands increase on players as teams usually play six matches over the course of two or three days in a tournament. A season consists of 10 tournaments being played all over the world. Successful teams maintained ball possession, less handling errors and conceded fewer turnovers, converted possession into tries and have solid defensive structures with high percentage tackle completion rate (Higham et al., 2014).

The last training session on the evening before the start of a tournament is referred to as the captain's run. This is usually a relatively short, low intensity training session to prepare for the games the next day. During this time last-minute planning can be done, but often the players just do a few “plays” (tactical formations of players performing an on-field task), practice a few calls (the on-field trigger for the team to perform certain tasks) or to “stretch their legs” and get into the “mindset” for the tournament. In contrast to other sessions, the captain usually takes charge of this session, however, it is at the discretion of the coach. This is an important event and was included in the study as this training session differs from the usual training session being a very low-intensity session. Furthermore, due to this session being the night before an event, players’ sleep might be influenced by other factors rather than that of the training session, such as match anxiety.

Sevens Rugby players need optimal training load stimulation as well as sufficient recovery to be competitive. Match demands placed on these players warrant frequent high-intensity training sessions to prepare for matches. Long flights to travel to various locations over the world for matches are prerequisites, but takes its toll on players (Kruyt & Grobbelaar, 2019). Sleep is seen as an essential part of recovery in elite athletes, however high-intensity training, late evening matches and travel across time-zones may hinder optimal sleep for players.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The current study addressed the dearth in the literature on the relation of different training load components of exercise on subsequent sleep, especially in team sports such as Rugby Sevens. In order to achieve the set objectives, intensity of training sessions (RPE), as well as the duration of training session were used to calculate training load. Perceived sleep quality and duration were also measured with the use of online self-reported diaries. This chapter provides a breakdown of the methodology that was applied which should provide the necessary particulars for it to be replicated.

3.2 Study Design

This study was a descriptive, explorative and longitudinal study conducted among players of the South African National Rugby Sevens squad. Because of this study being of observational design, no intervention took place. Data were collected during a complete competitive season over a period of seven months. Data collection started during the pre-season in November 2017 and conducted after the last match of the season in July 2018.

3.3 Participants

Professional male Rugby Sevens players (n = 16) from the South African National Sevens Squad were included in this study. These players competed at the highest international level of this sport code. The study was approved by the team's management and the South African Rugby Union (SARU). All players took part willingly and provided informed consent. All players met the inclusion criteria for this study. Sleep and exercise of players were recorded over 7 months of training and competition. Players were between the ages of 19 and 29 years. All were part of the national South African Rugby Sevens squad for the 2017/2018-season. Their physical characteristics are summarised in Table 3.1.

Table 3.1 Physical characteristics of the players assessed

Rugby Sevens Squad Physical Characteristics		
Participants	n = 16	
	Mean ± SD	**Range**
Age (years)	23.1 ± 3.4	19 - 29
Weight (kg)	84.1 ± 11.7	65.4 - 104.1
Height (cm)	179.9 ± 7.4	166.4 - 191.1

3.4. Inclusion and Exclusion Criteria

Players were included if they were professional male rugby players from the South African National Rugby Sevens squad for the 2017/2018-season. Data from players were included if there were a ‘record set’ for a day of the player. A ‘record set’ is defined as having a recorded training duration, intensity, training load, sleep duration and sleep quality for a day. Only scheduled training sessions with the squad were included. Matches and training data were included irrespective of players training or playing matches at home or away. Only training sessions, captain’s runs and match data were included. Data of players were excluded if they had long-term injuries preventing them from training with the squad. Data were not recorded on weekends when there was no formal training with the squad. Data were also not recorded when players were on “breaks” or on their days off from the squad when they also did not adhere to a formal training schedule. Furthermore, data from players were excluded from the study if they had a sleep disturbance score of more than eight as identified by the PSQI, as values higher than eight indicate sleep disturbances.

3.5 Ethical Aspects

The study protocol was approved by the Departmental Ethics Committee (DESC) and the Research Committee for Humanities at Stellenbosch University (SPORT-2017-1268) (Appendix A).

Before the pre-season training started in November 2017, the players were met at the Stellenbosch Academy of Sport (SAS) where the study procedures were explained verbally and presented visually. The study was approved by the team's management and the medical manager of the South African Rugby Union (SARU) granted permission for data collection and access to the players' individual training data (Appendix B). All participants provided informed consent to willingly participate in this study (consent form included in Appendix C).

Participation was voluntary, and all players were able to withdraw from the study at any time. A reason for withdrawal was not necessary. All data were treated with strict confidentiality and remained anonymous when reported on in the study. Data were stored on the researcher's password-protected personal computer, as well as an online back-up through password-protected cloud-based software, to which only the researcher had access. The researcher acted professionally and treated players and staff with respect at all times. All data used for analysis were safely and securely stored after the completion of the study. Due to the non-invasive nature of the data gathering techniques that are already commonly used in the modern game, there were no physical risks to the players as a result of this research.

3.6 Study Outline

Place of study

The Rugby Sevens squad was based at SAS, Stellenbosch, South Africa. Training took place on the surrounding sports fields and in the gymnasium at SAS. Players travelled to one local (Cape Town) and nine overseas locations during the study to compete in the HSBC World Rugby Sevens Series fixtures.

Procedures

On the first day of the study, all players completed the Horn-Östberg Morningness and Eveningness Questionnaire (MEQ) and the Pittsburgh Sleep Quality Index (PSQI). Carl Foster's Session RPE method (Foster et al., 2001) was used to collect RPE scores and to calculate Session RPE. The strength and conditioning (S&C) coach of the team collected an RPE score from each player verbally and individually within 30 minutes after the completion of each training session, captain's run or match. These scores were captured onto a Microsoft Excel workbook by the S&C coach and later uploaded onto the team's monitoring computer software application. The Rugby Sevens squad used an online monitoring system. Training and match data were uploaded via a web-based programme called 'Kitman Labs–Athlete Optimizing System' (Dublin, Ireland) where it was stored and maintained locally on the S&C coach's computer. Training was performed anytime during the day, and sessions were usually divided into morning sessions, mid-day sessions and afternoon sessions. These sessions were, however, frequently swapped around or replaced with other sessions in order to avoid the monotony of training sessions (Table 3.2).

Table 3.2 A typical training week for the squad when there were no matches on the weekend

	Monday	Tuesday	Wednesday	Thursday	Friday
08:00	Field	Tactical		Field	Tactical
09:00		Field		Field	Field
10:00					
11:00	Tactical	Field			Field
12:00		Gym		Field	Field
13:00	Gym			Field	Skills
14:00	Skills				
15:00		Gym			Gym
16:00					

Sleep information was captured by each player every morning after awakening. All players logged onto the “Kitman Labs” mobile application (Kitman Labs, Dublin, Ireland) with their mobile phones using their username and password and completed a questionnaire as part of the teams’ daily monitoring of the player. This was automatically uploaded to a secure cloud-based server where it integrated with the team’s Kitman Labs software application and could be viewed remotely by the coach, other team staff members and the researchers who had permission to access the RPE and Sleep data via a provided URL. Data were securely accessed and retrieved in a .csv format.

Table 3.3 The World Rugby Sevens Series 2017-2018-season fixtures and the country the tournaments were hosted in

Country	Tournament Name	Tournament Date
United Arab Emirates	HSBC Dubai 7's	1–2 December 2017
South Africa	HSBC Cape Town 7's	9–10 December 2017
Australia	HSBC Sydney 7's	26–28 January 2018
New Zealand	HSBC Hamilton 7's	3–4 February 2018
United States of America	HSBC Las Vegas 7's	2–4 March 2018
Canada	HSBC Vancouver 7's	10–11 March 2018
Hong Kong	HSBC Hong Kong 7's	6–8 April 2018
Singapore	HSBC Singapore 7's	28–29 April 2018
England	HSBC London 7's	2–3 June 2018
France	HSBC Paris 7's	8–10 June 2018

The squad competed in 10 tournaments during the season (Table 3.3). Each tournament always consisted of six matches, even if the final is not reached. Players flew to the destination of the tournament the week prior to the start of the tournament. Competitions were grouped in two "back-to-back" tournaments where matches were played on two consecutive weeks, except for one occasion. After each "back-to-back" tournament the squad flew back home (South Africa) and were allowed one week off from training or minimal training were done.

3.7 Measurements

Session RPE Method

Players were used to the concept of reporting RPE scores as part of the ongoing monitoring system implemented in the Rugby Sevens squad. Within 30 minutes of the termination of the exercise, the player was verbally asked, “How was your workout?”. Answers were given by indication the corresponding number to how the exercise session was perceived on the Modified Rating of Perceived Exertion Scale as depicted in Table 3.4 (Foster et al., 2001). The S&C coach captured the response on an Excel worksheet. The Session RPE method has been shown to be a valid method of monitoring internal load (Herman et al., 2006) and is one of the most frequent measurement methods used (Cardinale & Varley, 2017). It should be noted that for the purpose of this thesis, the use of the session RPE method and the terminology were slightly adjusted. For the current study, sRPE and the duration of exercise sessions and were collected. To determine the highest intensity for a day, the session with the highest RPE was used called the daily maximum RPE (mRPE). It should be noted that the mRPE concept was only used to determine the maximum RPE for a day with multiple sessions as session RPE is already a indication of the maximum exertion for a session. The maximum RPE score for the day was used instead of the average RPE scores for the day as it reflects the absolute maximum effort as perceived by the player for a training session on a specific day. Training load was not determined as a whole with mRPE, but rather all session RPE scores were multiplied by the session’s duration (the training load calculations are elaborated on further in this chapter). The RPE scale used range between 0 and 10 where 0 is the lowest and 10 the highest perceived exertion experience during the exercise session.

Table 3.4 Modified Rating of Perceived Exertion (RPE) Scale used to indicate the perceived exertion after each exercise session

Rating	Description
0	Rest
1	Very, Very, Easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very Hard
8	
9	
10	Maximal Effort

Training Load (TL)

Foster (1998) describes a measurement of the magnitude of training for a session called the Session RPE method. Session RPE is used to calculate load. This method of quantifying training load has been shown to correlate very well (between r = 0.75 and r = 0.90) with the sum of heart rate zone scores ($\sum HR\ Score$). This indicate that training load is a valid method of quantitating exercise training (Foster, 1998). This was adapted for the purpose of this thesis and the load for each session was called session training load (sTL). This was calculated as the product of session RPE (sRPE) (the score as seen in Table 3.4) and session duration (sDuration) for each session. Thus, for the purpose of this thesis: $Session\ Training\ Load\ (sTL) = sRPE\ \times sDURATION$ (Figure 3.1). Workload and training load can be used interchangeably for this thesis, however, for the purpose of this thesis, the term training load was used to quantify effort in training sessions and matches. $Session\ Training\ Load = sRPE\ \times sDURATION$

The magnitude of training for each day was termed daily training load (dTL). This was calculated by aggregating all the session training loads (sTL) for the day to give a single value: $Daily\ Training\ Load = \sum(sRPE\ \times sDuration)$. Figure 3.1 shows an example of the session duration, sRPE and the sTL data for training sessions as retrieved from the Kitman Labs System. For matches, the same principle was followed to obtain the daily training load, meaning, the RPE score after each match was multiplied by the match duration and the result was then aggregated to determine the daily training load for match days. To determine the maximum intensity for a day consisting of multiple matches on the same day, similar to training sessions, the highest RPE score of all the matches for the day was used as the daily maximum RPE.

			Workload		
Session	Day	Date	Duration	RPE	Load
Gym - Strength	Mon	01/04/2019	60 mins	6	360
Skills	Mon	01/04/2019	60 mins	5	300
Attacking Session	Tue	02/04/2019	45 mins	5	225
Defense Session	Wed	03/04/2019	-	-	-

Figure 3.1 *An example of the session duration (sDuration in this thesis), RPE (sRPE in this thesis) and Load (training load in this thesis) data for training sessions as retrieved from the Kitman Labs System.*

Longitudinal analysis

For the longitudinal analysis the mean daily training load, sleep quality and sleep duration for each week for all the players were calculated. The team average was then calculated for each week of the 31-week season and plotted against the corresponding week for the season. Only training data and captain's runs were included in the analysis and match data were excluded. This was done as training sessions were controlled by the coach.

Sleep Questionnaires

Players were asked to complete two once-off sleep questionnaires. The 16 players completed the questionnaires. The purpose of the questionnaires was explained to the players and feedback was given by supplying players with a report of the results of the questionnaire. Hard-copies of the Horn-Östberg Morningness and Eveningness Questionnaire (MEQ) (Appendix D) and the Pittsburgh Sleep Quality Index (PSQI) (Appendix E) were distributed and completed by the participants at SAS in Stellenbosch. The hardcopies completed by the participants were captured on a Microsoft Excel Spreadsheet for further calculations. These are two of the most widely used questionnaires in the field of measuring sleep abnormalities.

As was described in Chapter Two, the Pittsburgh Sleep Quality Index (PSQI) gives a comprehensive view of the respondent's past month of perceived sleep quality (Krystal

& Edinger, 2008). This questionnaire was found to be a reliable measurement of subjective sleep measurement for sleep problems (Buysse et al., 2008; Grandner et al., 2006). Also described in chapter two the Horn-Östberg Morningness and Eveningness Questionnaire (MEQ) measures individual circadian rhythms which are known as chronotypes (Horne & Östberg, 1976). This questionnaire was shown to be valid and reliable to be used as a scale for morning and evening type classification (Shahid, Wilkinson, Marcu, & Shapiro, 2012).

Sleep Diary

Sleep diaries to determine perceived sleep quality and sleep duration are often being used in the field and experts agree that this is a reliable methodology (Carney et al., 2012). For the current study, sleep dairies were recorded using the Kitman Labs-Mobile application (Dublin, Ireland). Every morning a questionnaire was completed on the Kitman Lab mobile application after the player woke up. This can be done either on a mobile phone, tablet or computer. There were two sleep-related questions. One question asked the player to enter the duration of the previous night's sleep as perceived by the player. The other question asked the player to indicate the perceived quality of the previous night's sleep on a scale from 1-10 where 1 is the worst and 10 is the best quality of sleep experienced (Figure 3.2). Sleep quality and refreshment after sleep using a scale ranging from 1 to 10 has often been used in other studies (Knufinke, Nieuwenhuys, Geurts, Coenen, et al., 2018). Perceived sleep quality is important for analysing the perception of sleep in subjects (Myllymäki et al., 2011).

All training load and sleep data exported from the Kitman Labs – web-based system was gathered and consolidated in a Microsoft Excel workbook from where the data processing was done before the statistical analysis could be performed.

Variable	24/02	25/02	26/02	27/02	28/02
Sleep Quality 1-10	-	10	10	10	10
Sleep Duration min	-	495	495	420	420

Figure 3.2 *An example of the sleep quality and sleep duration as retrieved from the Kitman Labs System for a player.*

3.8 Outcome Variables

An explanation of the outcome variables and a definition obtained from the measurements are summarised in Table 3.5. As was mentioned earlier in this chapter, Carl Foster's terminology of the Session RPE Method was adapted for the purpose of this study. Below follows an explanation:

Carl Foster's Session RPE Method:

- Session RPE x Session Duration = Session RPE Score (load)

In this study:

- Concept: Load = RPE x Duration

- To determine the load for a single training session: Session Training Load (sTL) = Session RPE (sRPE) x Session Duration (sDuration)
- To determine the load on a day for a single training session or multiple sessions: $Daily\ Training\ Load\ (dTL) = \sum(sTL)$ *note: all sTLs for a day.
- $Mean\ weekly\ Training\ Load = (\frac{\sum(dTL)}{n\ (weekly\ training\ days)})$ *note: all dTLs for a week.

Table 3.5 Summary of the outcome variables with descriptions relating to training and sleep as adapted from Carl Fosters Session RPE method and modified

Outcome variables	Description	Measure of
Session RPE *(AU)* ***(sRPE)***	The RPE score the player felt was most appropriate to describe the intensity of the exercise session performed on a scale from 1-10.	Exercise Intensity
Session Duration *(sDuration)* *(minutes)*	The time the exercise session lasted from start to finish in minutes.	Exercise Volume
Session Training Load *(AU)* **(sTL)**	The exercise session RPE is multiplied by the exercise duration to give the session training load.	Exercise Magnitude
Daily Maximum RPE Score *(mRPE)* *(AU)*	The highest RPE provided for any of the exercise sessions performed on a day	Maximum Exercise Intensity for the day
Daily Duration *(DD)* *(minutes)*	The aggregation of all the session durations for a day (in minutes).	Total Exercise Duration for the day
Daily Training Load *(AU)* **(dTL)**	Exercise session RPE scores are multiplied by the exercise session duration and then aggregated for the day	Exercise magnitude for the day
Perceived Sleep Quality *(pSQ)* *(AU)*	The sleep quality as perceived by the player for a night's sleep on a scale from 1-10	Quality of a night's sleep
Perceived Sleep Duration *(pSD)* *(minutes)*	The time asleep as perceived by the player during the night in minutes	Duration of a night's sleep

To limit the influence of co-founding variables, exercises were grouped in different exercise conditions. As presented in Table 3.6, for reporting purposes the total duration for all sessions during a day (DD), maximum RPE for the day (mRPE) and the total daily training load (dTL) were collectively called *Training Load Variables*. The self-reported perceived sleep quality (pSQ) and duration (pSD) were collectively called *sleep variables*. Training sessions, matches and captain's runs were collectively grouped as Exercise conditions.

Table 3.6 The contents of Training Load Variables, sleep variables and Exercise conditions

Training Load Variables:	Sleep Variables:	Exercise Conditions:
Daily Duration (DD)	Self-Reported perceived sleep quality (pSQ)	Training
Daily Training Load (dTL)		Captain's run
Daily Maximum RPE score (mRPE)	Self-Reported perceived sleep duration (pSD)	Matches

3.9 Data Capturing Process

A schematic presentation of the data capturing process of training, captain's runs, matches and sleep to obtain the final data set for the analysis of the training load and sleep quality and quantity is shown in Figure 3.3. From a total of 1478 night recorded with sleep duration and sleep quality, 756 were combined with training, 81 with matches and 78 with captain's runs. One captains's run was excluded. This gave a completeness ratio of 62% for nights with sleep recorded and used in the training load calculations.

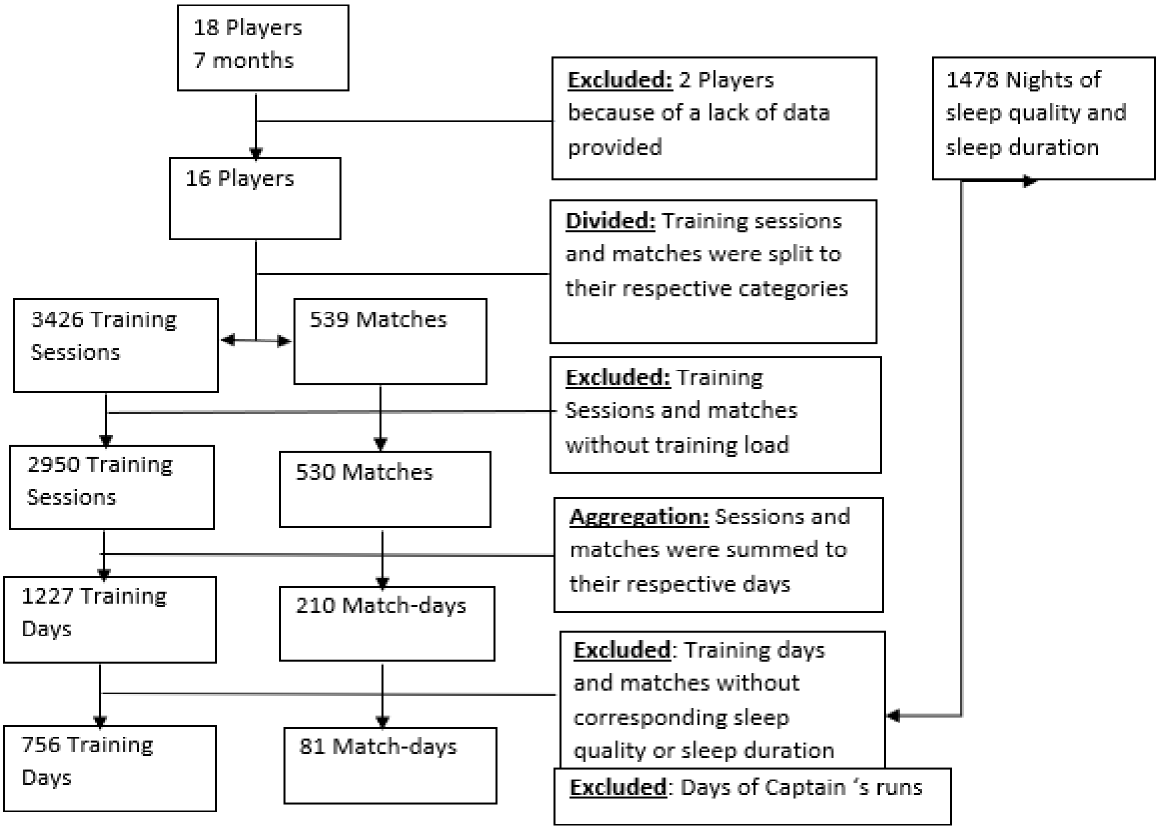


Figure 3.3. *A schematic presentation of the data capturing process of training, matches and sleep to obtain the final data set for the analysis of training load and sleep quality and quantity.*
**Note: the 539 Matches were the sum of all the matches of all the players*
**Note: Captain's runs were excluded from training days, but, was used in the captain's runs calculations.*

The following process was used for capturing of sleep data:

- 18 Players' data were originally included in the study.
- 2 Players were then excluded, because of a lack of data provided. The players did not have corresponding training or sleep data as they were only for a short while part of the squad. The rest of the players (n = 16) were monitored over a 7-month period.
- **1478** nights of sleep data that had both **sleep duration and sleep quality** were recorded over the season when all 16 players were combined (including captain's runs and matches) as this was longitudinal sleep data irrespective of training load.

The following process for the capturing of training data was used:

- First, all match days were separated from training days. This resulted in combined total training sessions of **3426** for all 16 players.
- Then, all training sessions that did not have corresponding training loads for the session were excluded from the dataset. The remaining total was **2950** training sessions with training loads (including captain's runs but excluding match days).
- Next, all the training sessions were aggregated to obtain a daily training load. This gave a total of **1227** training days (including captain's runs but excluding match days)**.**
- The nights where sleep quality and/or sleep duration or both were not recorded were excluded from the dataset. Training days were matched with the night's corresponding sleep data.
- Lastly, the days with captain's run were separated from the data set. This captain's run data were not completely discarded as it was used in the captain's runs calculations. The final total days for all players combined included in the dataset to be analysed were **756** Training days. This included training load, sleep quality and sleep duration for everyday. Captain's run-days and match-days are excluded form this data.

The following process for the capturing of match data was implemented:

- **539** Individual player match data sets were obtained.

- Nine matches without training load data were excluded to give a combined total of **530** matches with training load that were recorded for all 16 participants
- These 530 matches were aggregated to their respective match-days as more than one match could have been played per day**.**
- Next, matches were summed to their respective days per player, resulting in **210** match-days.
- Recorded sleep duration and sleep quality after match days were matched to the corresponding match days.
- Only **81** match-days had complete sets of training load as well as sleep duration and quality.

The following process for the capturing of training data on captain's runs was used:

- After training and match days were removed, **78** days with captain's runs remained which had training load and corresponding sleep duration and sleep quality. One of these data sets was removed as being an outlier and **77** data sets remained.

3.10 Statistical Analysis

For the descriptive purposes, means, standard deviations and range were used to report results. One-way ANOVA was used to test for mean differences between groups of various continuous measurements. Fisher least Significant Difference (LSD) was used for post hoc testing. Normality assumptions were evaluated by inspecting normal probability plots and were found to be acceptable in all cases. Levene's test was used to test for homogeneity of variance, and in cases where this assumption was rejected, the Welch test was done. However in all cases, the Welch test gave similar results to the ANOVA F-test, and therefore only F-test results were reported.

For correlations, Pearson and Spearman correlations were calculated, as well as repeated measures correlations to take into account the possibility that not all measurements were independent (Bakdash & Marusich, 2017). The results of the repeated measures correlations were reported on as this was the best fit for the analysis of this data.

3.11 Summary

Although numerous studies investigated exercise on sleep, few studies have investigated training load and its components on subsequent sleep, with no studies investigating the relationship between training load's components on subsequent sleep in Rugby Sevens. Furthermore, no studies have looked at longitudinal chronic training load and its components on sleep over a complete competitive season in Rugby Sevens. In order to achieve the objectives for this study, RPE and the duration of training were measured and used to calculate training load. Perceived sleep quality and sleep duration were measured by players completing a questionnaire on the Kitman Labs mobile application every morning. The data were allocated from training sessions, captain's runs and matches in order to control for confounding variables that might influence the results. Daily Duration, training load and maximal RPE of the exercise were correlated against perceived sleep quality and perceived sleep duration to measure for a relationship. The perceived sleep quality and quantity were also correlated against each other to test for a relationship. In addition, the mean daily training load, sleep quality and sleep duration for the team were plotted for each week of the 31-week season.

CHAPTER FOUR

RESULTS

4.1 Introduction

Results of the effects of exercise on the subsequent night's perceived sleep quality and duration will be discussed in this chapter. This chapter starts with descriptive statistics of the sleep questionnaires and of the Sleep and Exercise Variables. All the results pertaining to the relationship between Exercise Variables and perceived sleep quality and duration is then presented before ending with the results of the relationship between sleep quality and sleep duration.

4.2 Descriptive Statistics

Table 4.1 Physical characteristics of the players assessed

Rugby Sevens Squad Physical Characteristics		
Participants	n = 16	
	Mean ± SD	**Range**
Age (years)	23.1 ± 3.4	19 - 29
Weight (kg)	84.1 ± 11.7	65.4 - 104.1
Height (cm)	179.9 ± 7.4	166.4 - 191.1

Sleep Questionnaires

Pittsburgh Sleep Quality Index

The results of the 16 players who completed the Pittsburgh Sleep questionnaire at the beginning of the season were analysed. Of all the players assessed only two players did not fall within the range of good sleepers (PSQI > 5.0). However, these two players were only slightly outside of the range of good sleepers range, but were still acceptable as not having sleep problems as they were still below the cut-off of PSQI = 8. None of the players assessed reported any sleep problems. The mean score was 4.2 ± 2.04 and all players were in the range between 1 and 8.

Horn-Östberg Morningness and Eveningness Questionnaire

The players completed the Horn-Östberg Morningness and Eveningness Questionnaire (Horn-Östberg MEQ) at the beginning of the season. This questionnaire assesses circadian preference. Higher scores are an indication of morningness-type and lower scores indicate eveningness-type. All but three players fell in the middle of the scale indicating neither morning nor evening preference. Two players were 'moderately morning type' and one player fell into the 'definitely morning type' category. The mean score was 56.09 ± 6.88 with a range of 47 to 72.

Sleep variables for the different Exercise conditions

As shown in Table 4.2, the total recorded nights containing both pSD and pSQ accumulated to 1478 records. These were the total nights recorded regardless of preceding exercise or matches. Exercise conditions were used as a way to control for co-founding variables. Sleep variables recorded after training days accumulated to 756 while sleep variables recorded following match days were 81 and 78 following captain's runs, but were reduced to 77 as one data set was excluded as being an outlier. For all nights recorded (n = 1478), the average pSD was 07:49 ± 01:04 (hh:mm) and pSQ was 7.75 ± 1.67 out of a possible score of 10. For the 756 sleep records following training days the average pSD was 07:51 ± 00:55 (hh:mm) and pSQ was 7.72 ± 1.70. For the 81 sleep records following match days the average pSD was 07:43 ± 01:05 (hh:mm) and pSQ was 7.70 ± 1.70. For the 78 sleep records following days of captain's runs the average pSD was 08:08 ± 00:48 (hh:mm) and pSQ was 7.81 ± 1.68.

Table 4.2 Descriptive statistics (Mean ± SD) of daily duration, daily maximum RPE, daily training load and Sleep variables after the different exercise conditions

	Training	Captain's run	Matches	All Sleep datasets
Number of Days recorded n =	756	78	81	1478
Variables:	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Daily Duration (DD) *(Minutes)*	116.0 ± 53.2*	49.2 ± 14.5*	28.9 ± 12.9*	
Maximum Daily RPE Score (mRPE) *(AU)*	6.8 ± 1.5**	4.1 ± 1.3**	7.5 ± 1.8**	
Daily Training Load (dTL) *(AU)*	674.0 ± 317.9***	202.5 ± 103.6	206.1 ± 113.3	
Sleep Quality (pSQ)	7.7 ± 1.7	7.8 ± 1.7	7.7 ± 1.7	7.8 ± 1.7
Sleep Duration (pSD) *(Minutes)*	471.5 ± 55.2	488.9 ± 49.0#	463.5 ± 65.0	469.7 ± 64.0

Note: * denotes a significant difference for DD between training, matches and captain's run; ** denotes significant difference for m(RPE) between training, matches and captains runs; *** denotes a significant difference for dTL between training and the other exercise conditions;

# denotes a significant difference for pSD after Captain's run compared to the other exercise conditions.

AU = arbitrary units

As depicted in Figure 4.1, no significant differences were found for pSQ in any of the exercise conditions (p = 0.98). Captain's runs had the highest pSQ (7.8 ± 1.7) and matches the lowest (7.7 ± 1.7).

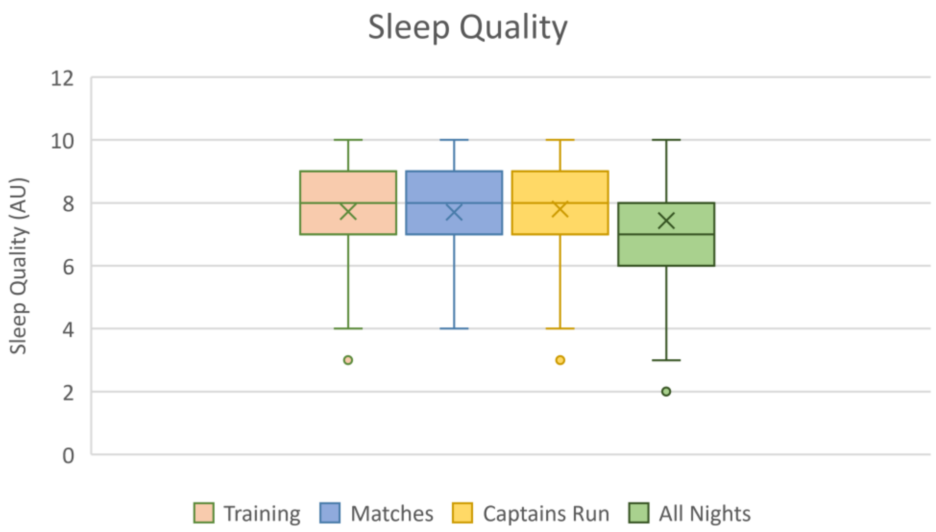
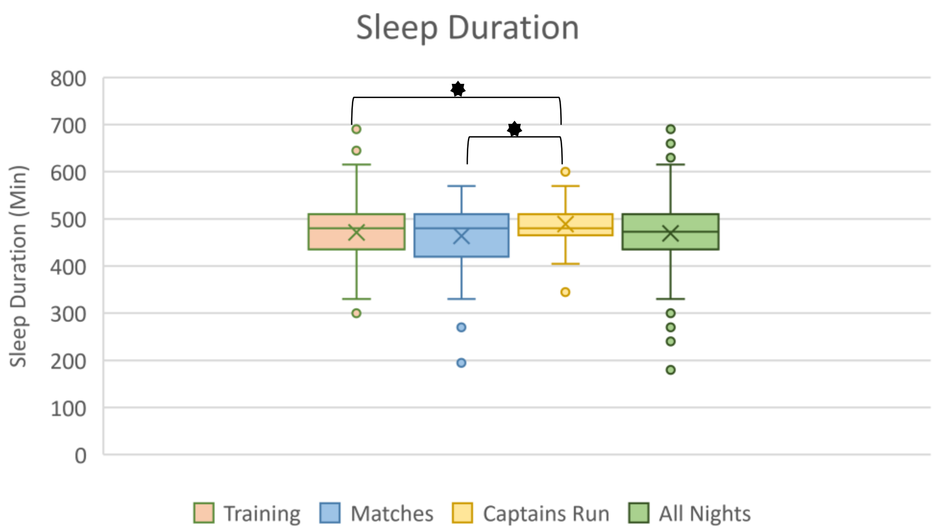


Figure 4.1 *Differences in self-reported perceived sleep quality compared after the three exercise conditions (training days, matches and captain's runs) and all nights recorded. There were no differences in sleep quality between the exercise conditions.*

As shown in Figure 4.2, only pSD on the nights after captain's runs (488.9 ± 49.0 min) was significantly higher ($p < 0.01$) compared to both training and matches. After match days pSD was the lowest (463.5 ± 65.0 min) followed by training (471.5 ± 55.2 min).

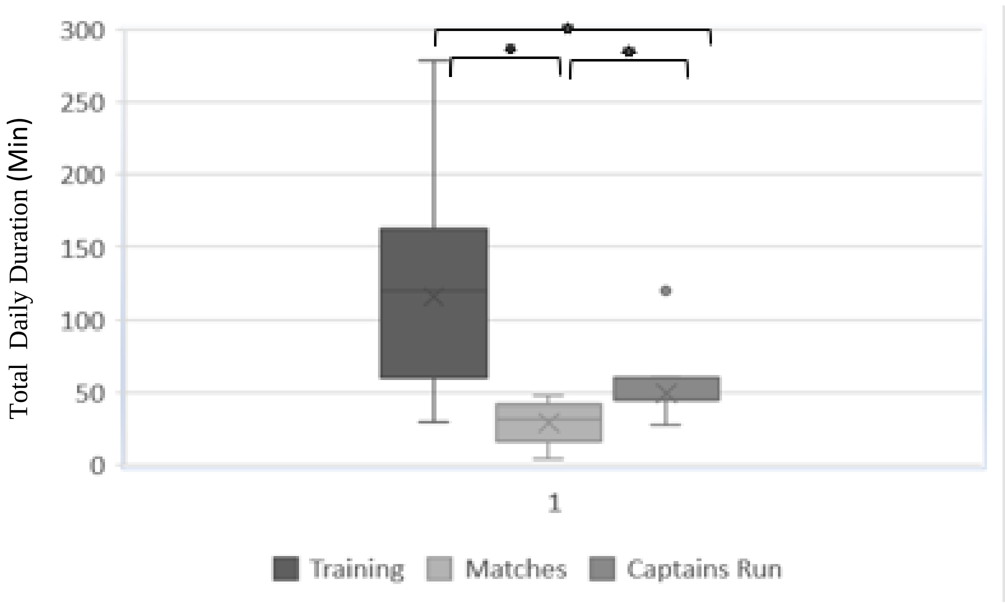


*P<0.01, significant difference for sleep duration between the captain's run and all the other exercise conditions.

Figure 4.2 *Differences in the self-reported perceived sleep duration after the three exercise conditions (training days, matches and captain's runs) and all nights recorded. This shows the sleep duration after captain's runs to the highest among the exercise conditions.*

Training Load Variables for different exercise conditions

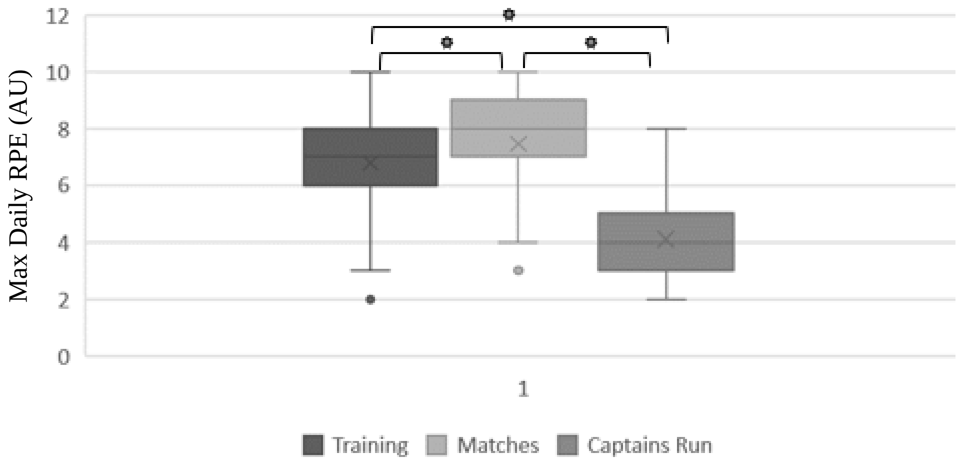
As can be seen in Figure 4.3, the daily average duration of training days (summation of sTLfor the day) (116.02 ± 53.23 min), captain's runs (49.24 ± 14.54 min) and match days (28.94 ± 12.93 min) all differed significantly from each other ($p < 0.01$). Training had the longest duration and matches the shortest.



*P<0.01, significant difference in the daily duration for training, matches and captain's run

Figure 4.3 *Differences in the daily duration of exercise sessions between the three exercise conditions (training days, matches and captain's runs). This shows training duration to be significantly higher the other exercise conditions.*

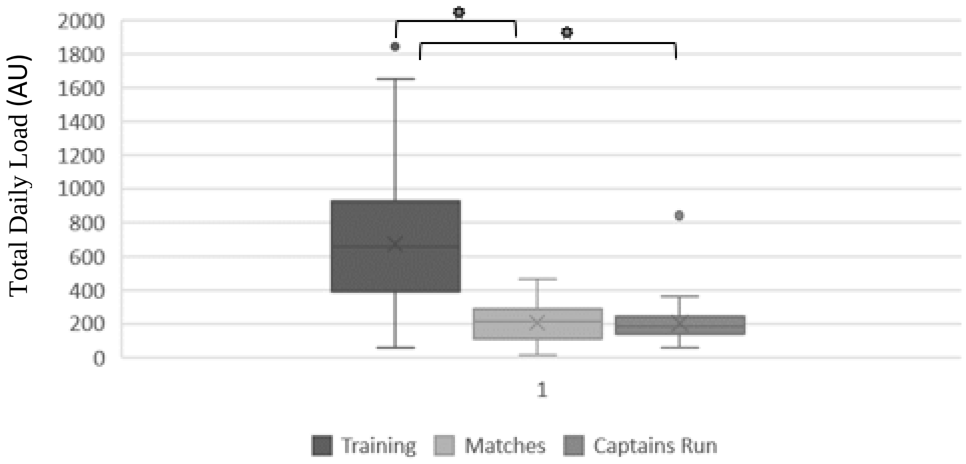
Daily maximum RPE differed significantly between all three of the Exercise Condition ($P < 0.01$) (Figure 4.4). Match days had the highest daily maximum RPE score (7.47 ± 1.76), followed by training (6.80 ± 1.54) whereas captain's runs had the lowest scores (4.1 ± 1.32).



* P<0.01, significant difference between the daily maximum RPE for training, matches and captain's run.

Figure 4.4 *Differences in the daily maximum RPE for the three exercise conditions (training days, matches and captain's runs). Maximum Daily RPE was the highest after matches and lowest for captains runs.*

The total daily training load (dTL) for training, matches and captain's runs can be seen in Figure 4.5. Daily training load for training days (674.07 ± 317.99 AU) was significantly higher than for match days (206.1 ± 113.3) (P < 0.01) and for captain's runs (202.5 ± 103.6) (P < 0.01). Daily training load for match days compared to captain's runs did not show any difference.



* P<0.01, significant differences between the daily training load for training and matches and training and captain's runs.

Figure 4.5 *Differences in the daily training load for the exercise conditions (training days, matches and captain's runs). This shows training load to be significantly higher for training days.*

4.3 The Relationship between Exercise Variables and sleep quality and quantity

Table 4.3 shows a summary of the findings reported below. During training 756 individual data sets of Exercise variables were recorded and correlated to Sleep variables. Likewise, 81 individual data sets of matches were recorded and correlated to Sleep variables. Lastly, after one data set was excluded, 77 individual data sets of Exercise variables during captain's runs were recorded and correlated to Sleep Variables.

Table 4.3 A detailed table showing the relationship between Exercise Variables and sleep quality and duration. A summary of this table is presented in Table 4.4. For easier reference the following text will refer to Table 4.4, however more detailed information can be found in this table.

Training Correlations between exercise variables and sleep variables						
Variable 1	Variable 2	rmcorr	p-val	lower 95%	upper 95%	# data sets
Total Daily Duration	Sleep Quality	-0.02	0.58	-0.09	0.05	756
Total Daily Duration	Sleep Duration	-0.16	<0.01	-0.23	-0.09	756
Max Daily RPE	Sleep Quality	-0.07	0.05	-0.14	0	756
Max Daily RPE	Sleep Duration	-0.12	<0.01	-0.19	-0.05	756
Total Daily Load	Sleep Quality	-0.03	0.38	-0.01	0.04	756
Total Daily Load	Sleep Duration	-0.17	<0.01	-0.24	-0.01	756

Match Correlations between exercise variables and Sleep Variables						
Variable 1	Variable 2	rmcorr	p-val	lower 95%	upper 95%	# data sets
Total Daily Duration	Sleep Quality	-0.4	<0.01	-0.59	-0.17	81
Total Daily Duration	Sleep Duration	-0.07	0.56	-0.31	0.18	81
Max Daily RPE	Sleep Quality	-0.18	0.15	-0.41	0.07	81
Max Daily RPE	Sleep Duration	-0.14	0.27	-0.37	0.11	81
Total Daily Load	Sleep Quality	-0.37	<0.01	-0.56	-0.13	81
Total Daily Load	Sleep Duration	-0.13	0.31	-0.36	0.12	81

Captain’s runs Correlations between exercise variables and Sleep Variables						
Variable 1	Variable 2	rmcorr	p-val	lower 95%	upper 95%	# data sets
Total Daily Duration	Sleep Quality	0.1	0.46	-0.16	0.34	77
Total Daily Duration	Sleep Duration	-0.04	0.74	-0.29	0.21	77
Max Daily RPE	Sleep Quality	0.23	0.08	-0.03	0.45	77
Max Daily RPE	Sleep Duration	0.22	0.09	-0.04	0.45	77
Total Daily Load	Sleep Quality	0.26	0.05	0	0.48	77
Total Daily Load	Sleep Duration	0.1	0.43	-0.16	0.35	77

- Rmcorr – Repeated Measured Correlation

a) The relationship between maximal RPE and perceived sleep quality

As can be seen in Table 4.4, no significant relationship was found between daily maximum RPE and pSQ for training, matches or captain's runs (P = 0.08). No correlation was found between daily maximum RPE and pSQ during training (r = -0.07).

b) The relationship between maximal RPE and perceived sleep duration

As can be seen in Table 4.4, only training showed a significant, but weak negative correlation between daily maximum RPE and pSD (r = -0.12) (P < 0.01). This is also depicted in Figure 4.6.

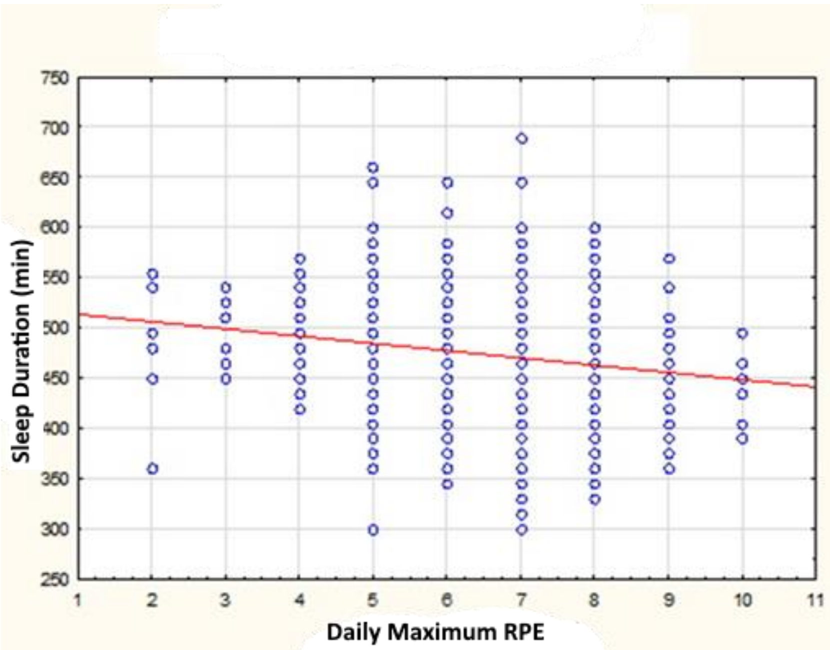


Figure 4.6 *The daily maximum RPE scores reported and the subsequent night's pSD after training sessions. There was a significant negative correlation for Sleep Duration and Daily Maximum RPE***.**

c) *The relationship between exercise duration and perceived sleep quality*

As shown in Table 4.4 the daily duration of training sessions and captains runs did not show a significant correlation with pSQ (P > 0.05). However, the daily duration of matches did have a significant, moderate negative correlation with pSQ (P < 0.01). Figure 4.7 shows daily duration of matches and pSQ having a moderate, but the significant negative relationship (r = -0.4).

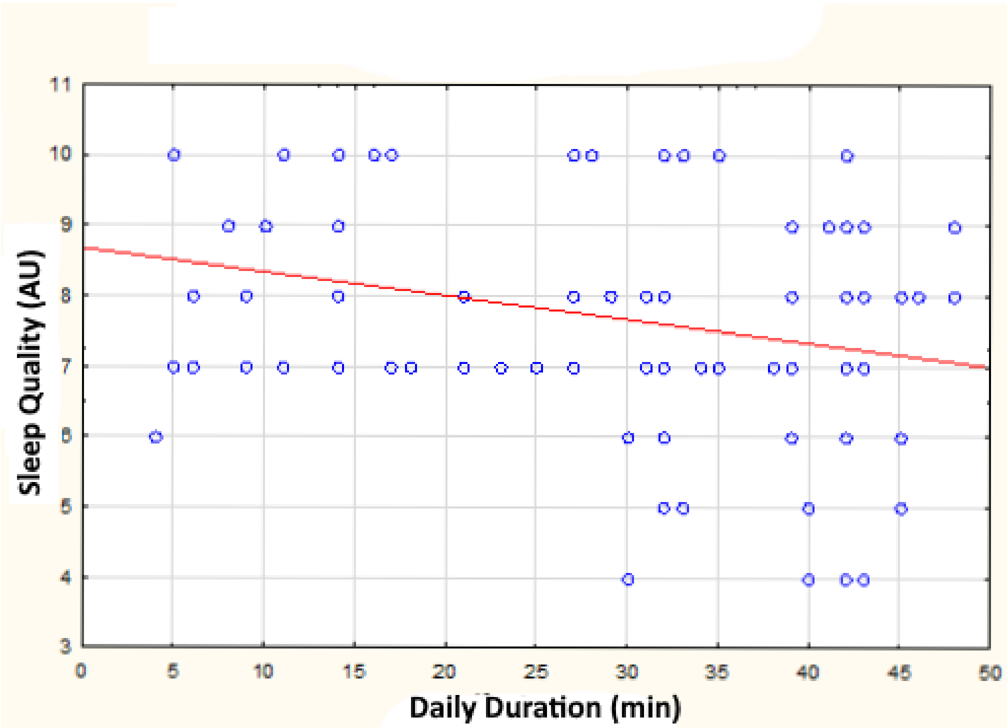


Figure 4.7 *The Daily Duration of matches correlated with the subsequent night's perceived sleep quality. There was a significant negative correlation between sleep quality and Daily Duration of matches.*

d) The relationship between exercise duration and perceived sleep duration

The daily duration of training sessions showed a weak, but significant negative correlation with pSD (r = -0.16) (P < 0.01) (Figure 4.8).

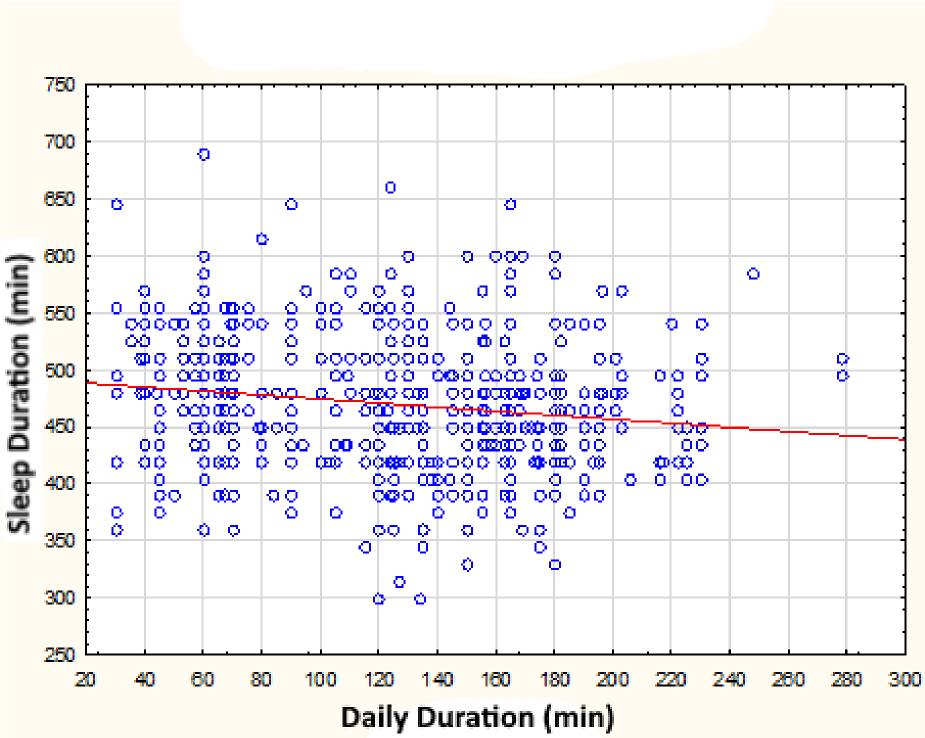


Figure 4.8 *A weak, but significant correlation between the daily duration of training sessions and sleep duration.*

e) The relationship between training load and perceived sleep quality

As depicted in figure 4.9 the daily training load of matches did show a significant weak negative correlation with pSQ (r = -0.37) (P < 0.01).

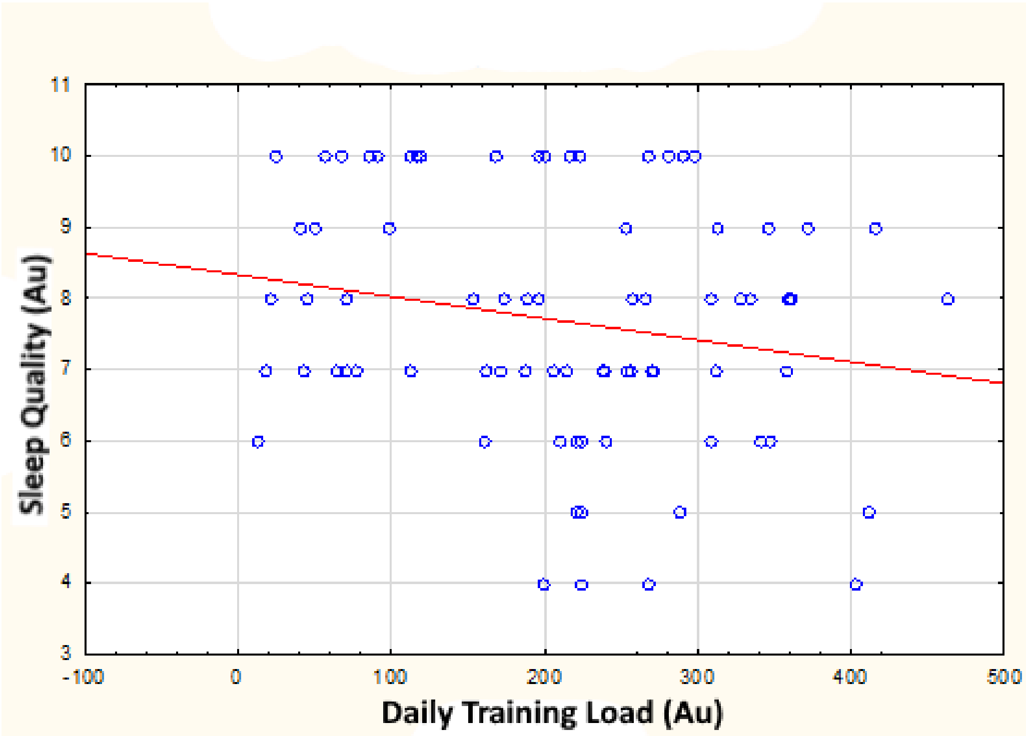


Figure 4.9 *The daily training load of matches showed a negative correlation with the subsequent night's sleep quality*.

f) The relationship between training load and perceived sleep duration

As shown in Figure 4.10 daily training load had a weak but significant negative correlation with pSD (P < 0.01) (r = -0.17).

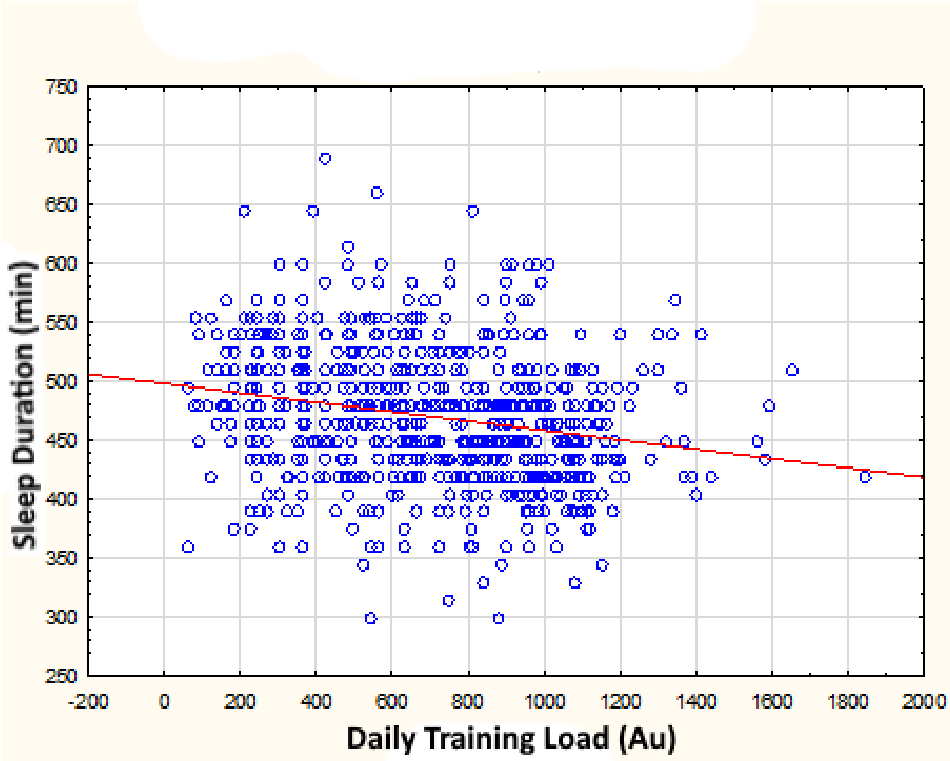


Figure 4.10 *The daily training load had a significant negative correlation with the subsequent night's perceived sleep duration.*

Table 4.4 This table is a summary of Table 4.3. The correlations between the daily training load variables and Sleep variables indicating significant correlations using repeated measure correlations. This table is only inserted as a summary of the results and for easier reference.

Training Load Variables	**Training**		**Matches**		**Captain's Run**	
	pSQ	**pSD**	**pSQ**	**pSD**	**pSQ**	**pSD**
Daily Duration	r = -0.02	**r = -0.16***	**r = -0.4***	r = -0.07	r = 0.1	r = -0.04
Maximum Daily RPE	r = -0.07	**r = -0.12***	r = -0.18	r = -0.14	r = 0.23	r = 0.22
Daily Training Load	r = -0.03	**r = -0.17***	**r = -0.37***	r = -0.13	r = 0.26	r = 0.1

$^*p < 0.01$

pSQ = perceived sleep quality
pSD = perceived sleep duration

4.4 The relationship between perceived sleep duration and perceived sleep quality

1478 nights of recorded sleep following days with or without training load variables. This included all the nights and not only the nights that corresponds to training load. This showed a statistically significant moderate positive correlation between pSD and pSQ (r = 0.32, p < 0.01). This is represented in Table 4.5 and the correlation is shown in Figure 4.11.

Table 4.5 Repeated Measure Correlation results for perceived sleep duration vs perceived sleep quality

Correlation between self-reported perceived sleep quality and self-reported perceived sleep duration						
Variable 1	Variable 2	rmcorr	p-val	lower 95%	upper 95%	Data sets
Sleep Duration	Sleep Quality	0,32	<0,01	0,28	0,37	1478

rmcorr – repeated measured correlation

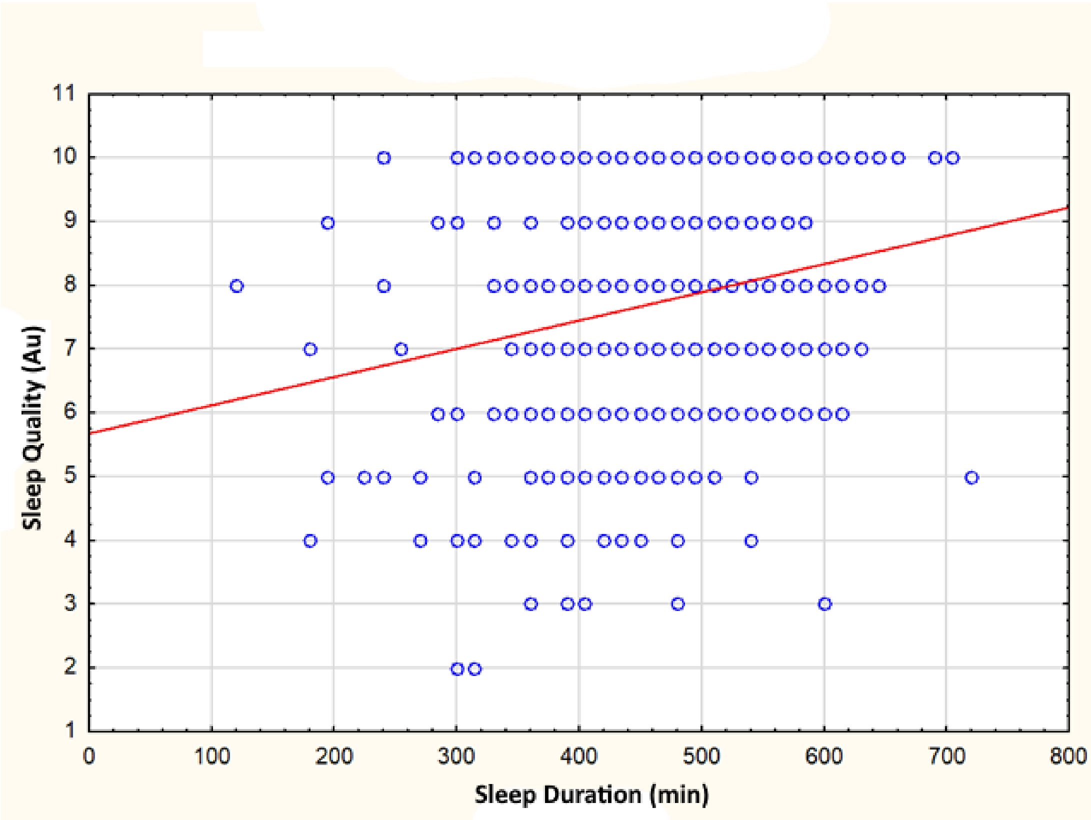


Figure 4.11 *Correlation between perceived sleep quality and perceived sleep duration for all recorded nights. There was a significant positive correlation for sleep quality and sleep duration.*

The relationship between sleep duration (grouped by hours of Sleep) and mean sleep quality

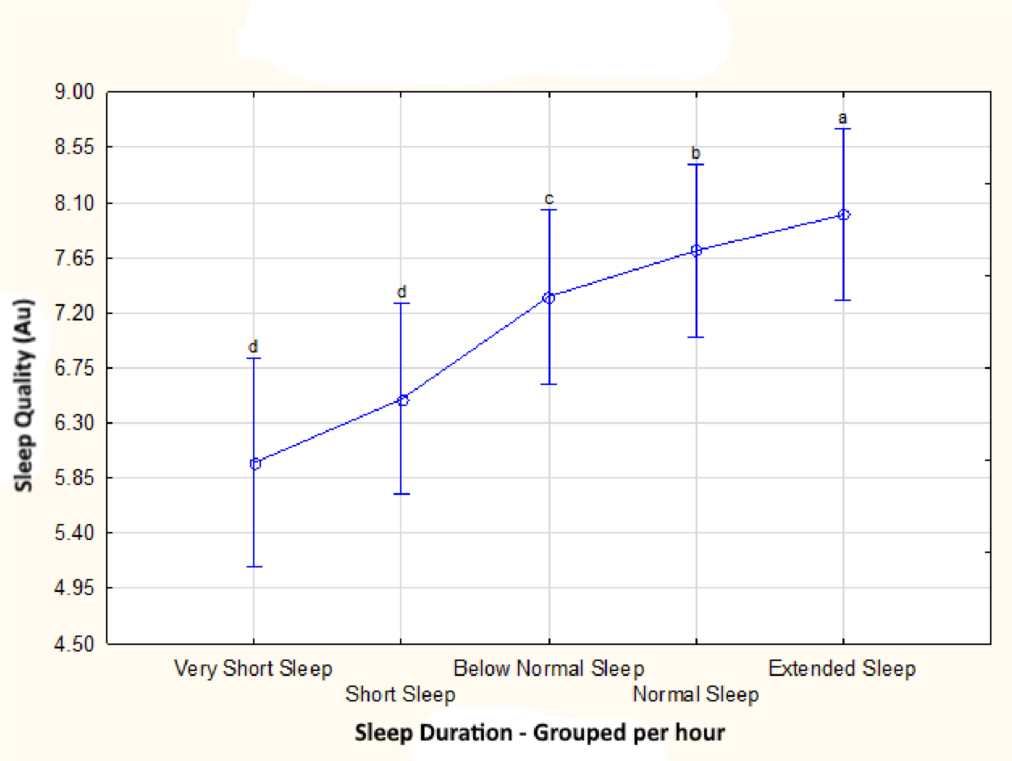
Shown by Table 4.6 is the descriptive statistics for the pSD grouped in hourly categories. Results of ANOVA on pSD groupings found a statistically significant difference. An LSD post hoc test showed a significant difference in all the hourly groupings of pSD and pSQ when grouped by hours of sleep ($p < 0.01$) except between short sleep and very short sleep ($p = 0.08$).

Table 4.6 Descriptive Statistics (mean±SD) for perceived sleep duration vs perceived sleep quality grouped by hourly sleep duration categories. This indicates a significant decline in sleep quality for every hour of decline sleep duration.

Descriptive Statistics			
Sleep Duration Grouping (hh:mm)	**Sleep Category Description (Duration)**	**Total data sets captured n**	**Sleep Quality**
		1478	**7.75 ± 1.67**
> 08:01	Extended Sleep	760	7.96 ± 1.52*
07:00 – 08:00	Normal Sleep	520	7.75 ± 1.67*
06:00 – 06:59	Below Normal	154	7.12 ± 1.89*
05:00 – 05:59	Short Sleep	29	6.55 ± 2.35*
< 05:00	Very Short Sleep	15	6.40 ± 2.03

*P < 0.01

Figure 4.12 shows a significant positive correlation between hourly pSD and pSQ. Extended pSD and pSQ showed the highest correlation and were significantly higher than Normal pSD and pSQ ($p < 0.01$). Normal pSD was significantly better correlated with pSQ than Below Normal pSD ($p < 0.01$) and Below Normal pSD and pSQ correlated significantly better than Short pSD and pSQ ($p < 0.01$).



a is significantly different from b (p<0.01)
b is significantly different from c (p<0.01)
c is significantly different from d (p<0.01)

Figure 4.12 *Perceived sleep duration grouped by hourly categories and the mean perceived sleep quality for each hourly category. Indicating a significant decline in sleep quality for every hour of decline sleep duration.*

4.5 Longitudinal Analysis

The team's mean daily training load, sleep quality and sleep duration for each week were plotted against each corresponding week during the 31-week season. Not training load, sleep quality or sleep duration showed a significant change from the beginning to the end of the season, however, using the Pearson correlation, training load showed a slight decrease (r = -0.04, $p > 0.05$) whereas sleep quality (r = 0.24, $p > 0.05$) and sleep duration (r = 0.18, $p > 0.05$) showed a slight increases. This is represented in Figure 4.12, 4.13 and 4.14 respectively.

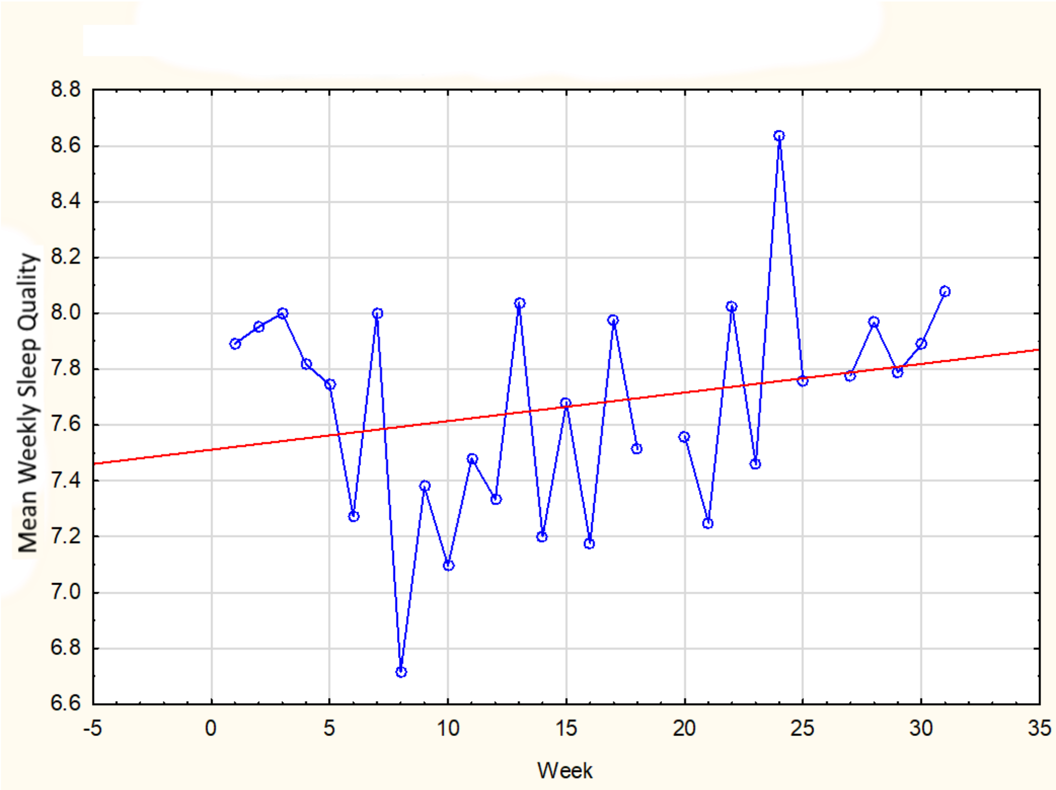


Figure 4.12 *Mean daily sleep quality per week for the team during the season of 31-weeks. There was not a significant change during the season, however, there was a slight increase from the beginning of the season to the end.*

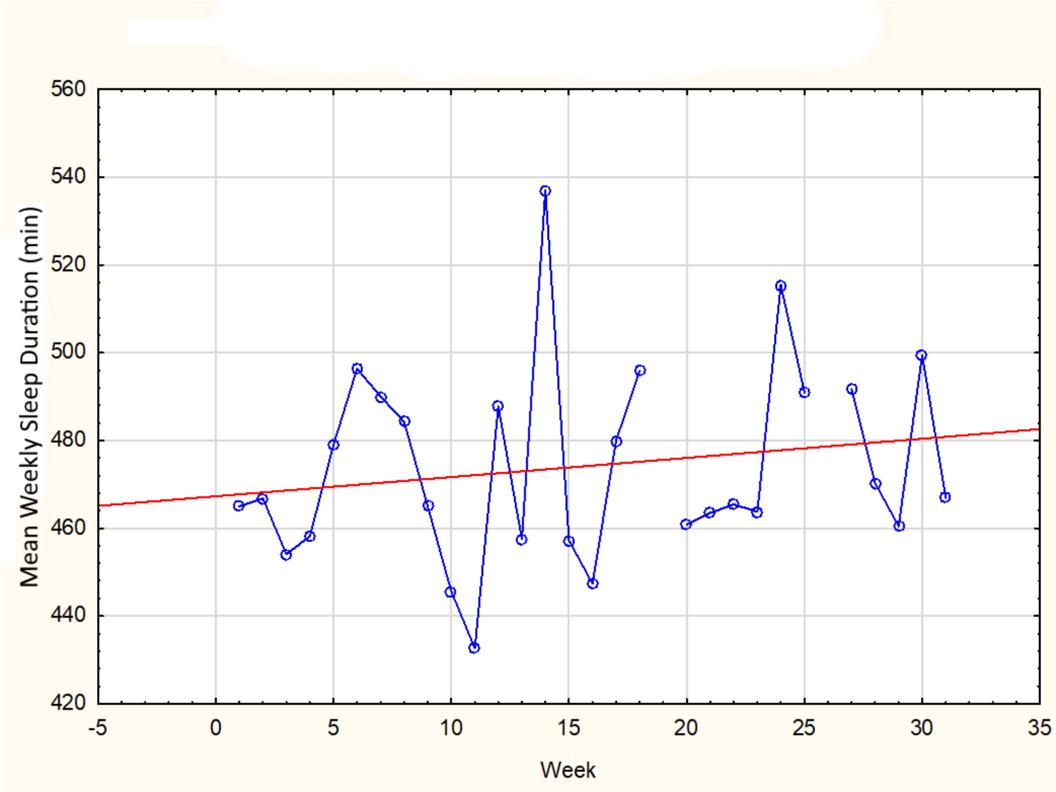


Figure 4.13 *Mean daily sleep duration per week for the team during the season of 31-weeks. There was not a significant change during the season, however, there was a slight increase from the beginning of the season to the end.*

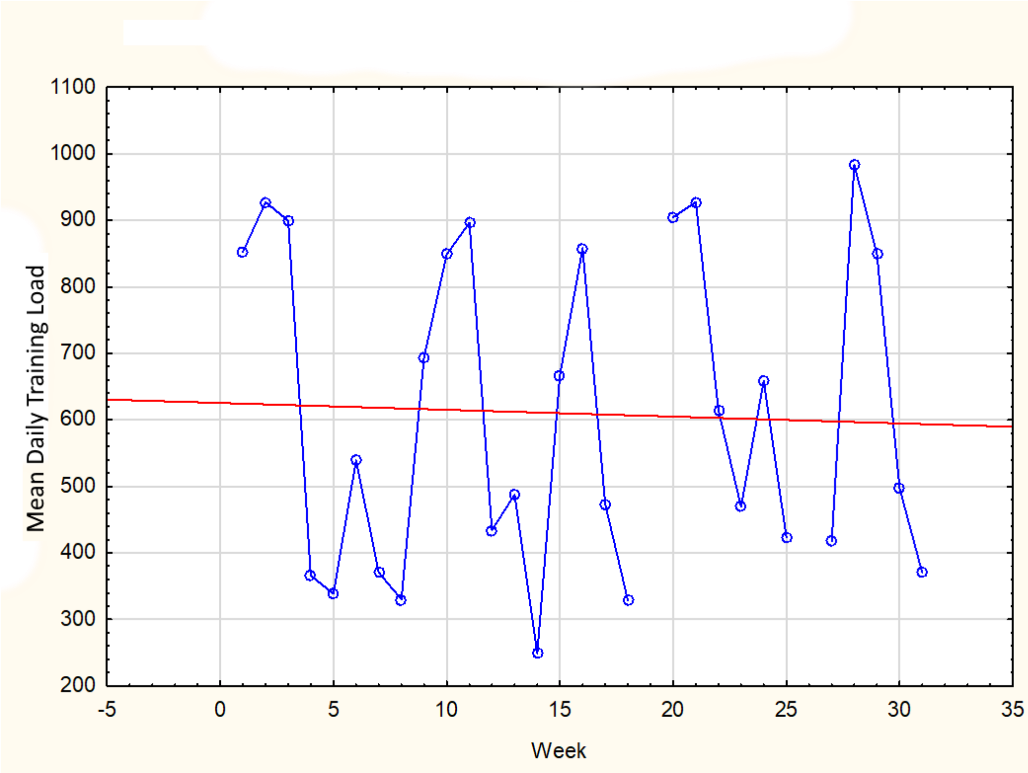


Figure 4.14 *Mean daily training load per week for the team during the season of 31-weeks. There was not a significant change during the season, however, there was a slight decrease from the beginning of the season to the end.*

CHAPTER FIVE

DISCUSSION

5.1 Introduction

The impact of day-to-day variation in training load on sleep quality and sleep quantity during a competitive season is unexplored in Rugby Sevens. Also, longitudinal data on training load, sleep quality and duration during a complete season was investigated. It is important to understand the relationship between sleep and various exercise modalities as the reciprocal effect of sleep on exercise has been shown (Chennaoui et al., 2015). The current study, therefore, aimed to determine the relationship between exercise and the subsequent night's sleep. This was determined in a sample of elite professional Rugby Sevens players. Players were monitored for seven months during training, matches and captain's runs. The duration, Maximum RPE and training load of exercise sessions, matches, and captain's runs were correlated with the following night's perceived sleep quality and perceived sleep duration. Sleep monitoring during a competitive season is valuable to coaches and trainers as it assures that athletes could assist with strategies to help players get the required amount of recovery, as would be expected after strenuous exercise. The findings of this study will allow S&C coaches to take into account the effect of exercise on players' sleep. The tool used in the current study was self-reported, feedback from the players on their perceptions of exercise effort and sleep. This can easily be administered in teams as it is inexpensive, non-invasive and usually relatively easy to interpret

This discussion will, firstly, present descriptive characteristics of the players in terms of overall findings within the team, followed by a discussion on the differences in the sleep variables for the different exercise conditions measured. The next section will discuss the primary findings of the study according to the research aims and objectives stated. Lastly, the limitations in the study will be addressed, suggestions for future research will be made, and a final conclusion to the study will be presented.

5.2 Descriptive Characteristics

All participants (n = 16) were professional, elite Rugby Sevens players. None of the players had any known sleep disorders and none of the players reported any sleep problems during this study. This was confirmed by the Pittsburgh Sleep Quality Index as all players fell within the acceptable range of not having sleep problems. Players were not extreme morning or evening types as tested using Horn-Östberg Morningness and Eveningness Questionnaire . Although a few players did gravitate more to morning-type as opposed to evening-type, only one player was a definitely morning-type. This is important to note to control for confounding variables, as very early morning and very late-night training sessions or matches might have an influence on performance or perceived exercise session intensity.

This study showed summed training sessions for a day to have a significantly longer duration compared to the summed duration of matches played on a day and captain's runs. Also, summed training sessions for a day had a significantly higher training load compared to summed duration of matches played on a day and captain's runs. Longer training sessions and higher training load compared to matches and captain's run were expected. The duration of a match is 14 minutes in total. Training sessions would be longer due to various aspects related to match-play that players have to prepare for and physical training that has to be implemented.

Overall, the average pSD was found to be 07:49 ± 01:04 (hh:mm). This is remarkably similar to Knufinke, Nieuwenhuys, Geurts, Møst, et al., (2018) who monitored 98 elite Dutch athletes for seven days using actigraphy and reported an average of 07:50 ± 01:08 hh:mm sleep time. There are thus similarities between the current study's sleep duration and the study of Knufinke and colleagues (2018), even though, one study measured perceived sleep and the other measured sleep objectively. Subjective sleep duration has been shown to correlate well with objective measures of sleep duration (r = 0.85), however subjective sleep duration has been shown to be overestimated by an average of 19.8 minutes (Caia et al., 2018). This is a possible reason for the difference found compared to (Leeder et al., 2012) who aimed to generate normative sleep data for the elite athletic population. They found time in bed to be averaged at 08:26 ± 0:53 (hh:mm) and total sleep time at 06:55 ± 0:43 (hh:min) for Olympic athletes. The difference might be explained by the difference in sleep monitoring tools used and this again shows a difference in subjective versus objective measurements. Other reasons for the difference might be the measuring of athletes out of season which might influence sleeping duration. Sleep duration was also found to be grossly overestimated in collegiate basketball players as subjective sleep scoring reported a baseline of 470.0 ± 65.9 min compared to 400.7 ± 61.8 using actigraphy (Mah et al., 2011).

5.3 Exercise conditions and sleep variables

The rationale for comparing the exercise conditions with each other was to try and limit co-founding influence on the data. The behaviour of players are different after training, before matches and after matches, including factors such as anxiety before matches, these conditions should be viewed in isolation. This study showed training sessions to have a significantly longer duration compared to matches and captain's runs. It should be kept in mind that there might be multiple training sessions on a training day and multiple matches on a match day. Also, training sessions had a significantly higher training load compared to matches and captain's runs. This is important to note, as the average sleep duration for training was not significantly affected, but as will be later discussed, training sessions showed negative correlations between exercise variables and sleep duration, showing sleep duration to be vulnerable after training days. Matches had a significantly higher average mRPE score compared to training and captain's runs. This is a clear indication that playing matches are significantly more intense for players than training and captain's runs. This finding is also of importance as the average sleep quality did not change for nights after matches. Furthermore, matches were the only exercise condition in which the exercise variables significantly correlate negatively with sleep quality. Although not significant, the only exercise condition which showed a notion for a positive correlation with sleep duration was captain’s runs. Captain’s runs had the lowest daily maximum RPE scores as well as the lowest daily training load indicating that players achieved the planned exercise session’s goal not to exhaust themselves the day before the start of the tournament. Also, of importance is that the average sleep duration was significantly longer the night after captain’s runs. The average sleep quality did not differ significantly between any of the exercise conditions indicating that on face value the average perceived sleep quality experienced after any of the exercise conditions are similar, contrary, to the widely held perception that the quality and the duration of sleep decrease before a competition. In this study, sleep duration was found to be the highest before a competition and the lowest after a competition.

Sleep duration and exercise conditions

Average sleep duration was significantly longer on the night after the captain’s runs compared to training and matches. This is in contrast to the belief that sleep duration is impaired before a competition (Roberts et al., 2019). The current study is in agreement with the prognosis review study by Stuart et al. (2019). They found total sleep time is the longest and sleep efficiency the highest the night before competition compared to after training or the night following the competition. This is similar to Shearer et al. (2015) who also found elite rugby union players to increase sleep duration prior to competition. More evidence of this was found on elite Australian Football players who also had the shortest duration of sleep the night after the match compared to other nights relative to the match. They also found sleep duration during periods of matches were shorter than during pre-season training (Lalor, Halson, Tran, Kemp, & Cormack, 2018). Other studies also showed sleep duration and sleep efficiency to be the best before a competition and worst the night after the competition, however, in all of these conditions reviewed the recommended values for neither sleep duration nor sleep efficiency was reached (Roberts et al., 2019). This was different from the current findings as sleep duration was found to be slightly more than eight hours the night prior to competition. This is in contrast to other literature reporting sleep duration before an event to be reduced with athletes not getting the required amount of sleep (Donnell et al., 2018; Lastella et al., 2014; Lastella, Roach, Halson, & Sargent, 2015). Australian team sport athletes were reported to obtain 7:36 ± 0:54 of sleep prior to an event and it is important to note that sleep durations were also estimated by the participants (Juliff et al., 2015). One explanation for the difference in findings compared to literature might be clarified by (Fullagar, Skorski, et al., 2015) as sleep loss prior to competition seems to be common in individual athletes, less so in team sports. This might be as a result of team sport players being in a supportive environment, sharing the responsibility compared to individual athletes who are individually responsible for the results.

Findings in this study present sleep duration after matches being the lowest and before matches being the highest. This is similar to O’Donnell et al. (2018) who studied netball players and found sleep duration to be reduced after matches compared to training sessions. Higher cortisol levels after matches show the high level of psychological stress experienced during matches. However, this is in contrast to Lastella et al. (2015) who studied various team and individual sports and found sleep duration the night before the competition to be the lowest and the night after competition to be higher. The use of different sport codes might cause these results to differ as team sports and individual athletes seem to respond differently to sleep prior to competition.

Sleep quality and exercise conditions

Interestingly, average perceived sleep quality did not show any significant difference after training, matches or captain's runs, indicating a very similar average perceived sleep experience between these three Exercise conditions. A similar finding was reported by Teng et al. (2011) who found that cyclists did not report any significant change in subjective sleep quality between baseline, a high training period or a taper period even though objective measures using actigraphy did show a decrease in sleep quality. As subjective sleep quality values increase over each period, Teng et al. (2011) speculated that athletes might be inaccurate when reporting their own sleep quality. Another reason suggested by the authors was that during a high training phase athletes are so exhausted that they assume they are sleeping better, but are not aware of the sleep disruption and less than optimal recovery during the night (Teng et al., 2011). Similarly, there was no difference recorded in sleep ratings during a pre-season period and a competition period. Sleep efficiency measured using actigraphy was lower during competition periods than during pre-season (Lalor et al., 2018). In contrast to general belief, some studies found sleep efficiency to be higher the night prior to competition as opposed to the night after a competition. Sleep efficiency and sleep quality might be closely related (Roberts et al., 2019). Meta-analysis studies found sleep quality to be affected by training, but even more the night before major competitions (Gupta et al., 2017).

One possible explanation for not finding any significant difference for sleep quality between Exercise conditions might be that when averaging sleep quality for each Exercise Condition, self-reported perceived quality is not sensitive enough to emphasise differences in the different Exercise conditions (Lalor et al., 2018). In contrast to this, some studies in the literature reported poor sleep quality the night before an event (Silva et al., 2012). One study showed 64% of Australian team sports athletes had sleep problems the night prior to competition, the main reasons being nervousness and thoughts prior to competition (Juliff et al., 2015). Lastella et al. (2014) reported 70% of athletes experiencing sleep problems the night before an event. However, they could not find any evidence that sleep difficulties before an event have any relationship to performance. Erlacher, Ehrlenspiel, Adegbesan, and El-Din (2011) conducted a survey on 632 German individual and team sports athletes. Of these athletes 66% slept worse the nights before competition than on other nights. Even though Ehrlenspiel et al. (2018) acknowledged the literature to be contradicting, they found a significant decrease in sleep quality the night prior to competition on elite German athletes.

It was anticipated that before match days, sleep quality might be influenced by confounding factors such as nervousness and increased sympathetic activation (Driver & Taylor, 2000). However, this was not reflected in the current study's findings. There might be two plausible explanations for the contradicting evidence in these results compared to the literature. One explanation could be that the experience level of the player is of importantance. Nervousness and anxiety in professional athletes might be reduced before competition due to many years of experience. Another explanation might also be as discussed by Erlacher et al. (2011). In their study, team sports athletes are less prone to pre-competition anxiety, because of a shared-responsibility compared to individual athletes who are individually exposed to the results or outcome of the competition and cannot share this psychological burden (Roberts et al., 2019). This might also be a reason why team sports athletes experience less anxiousness compared to individual athletes. Irrespective of this, Gupta et al. (2017) reported half to one-third of athletes being poor sleepers.

5.4 Research aim one: the relationship between exercise and sleep

The first aim of the current study was to determine if there is a relationship between perceived training load and self-reported sleep quality and quantity in professional Rugby Sevens players over a 31-week competitive season. This was determined by investigating the null hypotheses that were set. Exercise duration, exercise intensity and training load's relationship with subsequent sleep quality and sleep duration are discussed below.

a) Relationship between training load and sleep quality and quantity

It was hypothesised that a higher training load during training sessions, matches and captain's runs will not result in lower sleep quality or shorter sleep duration during the subsequent night's sleep. This hypothesis was accepted. There was a significant decrease in sleep duration with higher training load after training sessions. A higher training load also significantly decreased sleep quality after matches. Looking at the correlational data there seems to be a notion that sleep duration might be more prone to decrease after training sessions with a high training load whereas sleep quality showed a negative relationship with an increase in training load of matches.

As training load was significantly higher for training sessions than for matches this might provide a reason why training load only showed a significant negative relationship with sleep duration after training days and not after matches. It might be possible that the training load must reach a certain threshold, which is reached after training days, but not after matches. Similar results were found in another study measuring training loads in Rugby Sevens players during pre-season training. Comparing the week with the highest training load to the week with the lowest, the researchers also found a small decrease in total sleep time with periods of high training loads (Leduc et al., 2019). A similar finding was made by Kölling et al. (2016) when studying highly trained youth rowers at a training camp. Total sleep times were decreased when training volume and intensity were high, and this was reversed when the training load was lowered. The authors named early-morning training sessions as possibly one of the main reasons for sleep restriction, resulting in reduced sleep duration (Kölling et al., 2016). Two other studies recorded training load on sleep duration during training camps (one on rugby league and one on Australian rules football), also found sleep duration to be decreased with an increased training load (Pitchford et al., 2017; Thornton et al., 2016). They also attributed this decrease in sleep duration to early training times leading to sleep restriction.

Evidence for a training load threshold has been suggested, where sleep duration decreased if the threshold was surpassed and could be reversed with periods of reduced training load (Shapiro et al., 1981; Stuart et al., 2019; Teng et al., 2011). Although decreased sleep duration has been observed for functional-overreached athletes (Hausswirth et al., 2014), there was no knowledge of reports from players in this study being overreached. It thus do not seem like a plausible explanation for the results found. Given this evidence, it was difficult to separate direct and indirect pathways of exercise-induced changes to sleep from each other (Chennaoui et al., 2015). The significant reduction in sleep duration might not only be caused directly by the training load, but might be caused indirectly in cases such as early morning training sessions which reduce sleep duration for the athletes (Kölling et al., 2016; Thornton et al., 2016). This is confirmed by (Roberts et al., 2019) who found sleep duration to be shorter on training days than on rest days. There does not seem to be physiological benefits to early morning training, but a full daily schedule, access to training facilities or the outside environment might dictate training times (Lastella, Roach, Halson, & Sargent, 2015).

In contrast to the findings of the current study, a study on highly trained Dutch athletes showed no change in sleep duration with day-to-day varying training load (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). The authors mentioned that the training load might not have been extreme enough to affect sleep duration as the reported values were low. It was suggested that exercise may result in longer sleep duration, but this should be seen as a normal physiological process for the body to recover and adapt (Kjeldsen et al., 2012). Studies, where increased sleeping duration was found with higher training volume and intensity, may be explained by the possibility of the increased recovery need (Lastella, Roach, Halson, & Sargent, 2015; Leduc et al., 2019).

There are numerous physiological theories that contribute to possible explanations for the disruption of sleep duration after exercise. One such theory is the thermoregulatory theory where changes in core temperature could disrupt sleep onset (Nédélec et al., 2015) as training load is directly proportional to body temperature (Driver & Taylor, 2000). However, body temperature has been shown to return to normal rapidly after termination of exercise (Buguet et al., 1998). Also, because training sessions of the current study usually seized early in the afternoon, the subjects would have experienced limited exposure to higher body temperatures in the evening, limiting its effect on sleep duration. Changes in core body temperature might thus only have been an addition to the outcome of a reduced sleep duration after training. The theory of the HPA being overloaded due to circulating cortisol and sympathetic activity also does not seem to be the main reason for a reduced sleep duration after training as the subject used in this study were elite sportsmen and conditioned for high training loads.

Of interest were that sleep quality after matches negatively correlating with higher training loads, but not after training sessions. One possible explanation for this might be that training volume was not high enough to disrupt sleep quality after training. However, after matches sleep quality is more prone to be affected as body soreness and late-night matches arousal might impact sleep quality. The same level of muscle and body soreness combined with match arousal are not evident with training. This notion is supported by Miller et al. (2017) who also found sleep disturbance to be more prominent in sports codes with high aerobic demands in combination with the high physical impact of collisions, such as Australian Rules football compared to rugby union and soccer. They concluded that this might be related to more physical pain during sleep, because of the nature of the sport. It has been reported by other studies that contact sports athletes are more vulnerable to sleep disturbances (Nedelec et al., 2018).

There are studies showing a decreased sleep quality with higher training load in Rugby Sevens after training sessions, but not after matches. High training load during a Rugby Sevens pre-season training camp showed a small to moderate reduction in subjective sleep quality with high training loads. Objective sleep markers using actigraphy did not show any decrease in sleep quality, which emphasises the value of subjective sleep reporting (Leduc et al., 2019). In contrast to Leduc et al. (2019), the subjective sleep quality scores of cyclists did not significantly change, while objective measures of sleep quality were altered over a period of intensified training. It was reported that it is possible that subjective sleep quality is reported incorrectly and the feeling of exhaustion after periods of intensified training makes the athlete believe to sleep better irrespective of the quality required for optimal recovery (Teng et al., 2011).

Numerous other studies showed decreased sleep quality in team sports with increased training load (Fullagar, Duffield, et al., 2015; Pitchford et al., 2017; Thornton et al., 2016). Driver and Taylor (2000) also concluded in their review study that even though the effects of exercise on sleep seems modest, very long exercise durations at high intensities may disrupt sleep. It should also be kept in mind that high training loads during the day may result in stronger feelings of fatigue, which potentially may cause a more pronounced miss-scoring of sleep (Kjeldsen et al., 2012).

b) Relationship between exercise intensity and sleep quality and quantity

It was hypothesised that exposure to more intense exercise sessions will result in lower sleep quality or shorter sleeping duration during the subsequent night's sleep. This hypothesis was accepted. Exercise intensity had a significant negative correlation with sleep duration, but only after training sessions. Neither match intensities nor captain's run intensities had an effect on sleep duration. Although it has been suggested that high-intensity training significantly reduces sleep duration in elite sports (Gupta et al., 2017), these findings are not consistent and most studies in literature found the opposite. Myllymäki et al. (2012) did not find any change in sleep duration when acute exercise sessions were performed at high intensity (Myllymäki et al., 2012). Also, Horne and Staff (1983) found no difference in sleep duration with exercising at high intensity for short durations, but did find an increase in sleep depth measured as slow-wave sleep. Similarly, to the thermoregulating theory, it was suggested that exercise in itself does not cause an effect on sleep, but rather the change in body-heat accompanied by a greater fall in body temperature. Furthermore, using sleep scores as well as actigraphy did not show any difference in sleep duration after high-intensity exercise in soccer players (Robey et al., 2014) and a study on netball players showed that they experienced a significant reduction in sleep duration after matches, but not after training sessions (O'Donnell et al., 2018).

Even though there was a negative correlation between the intensity of matches and sleep duration, the intensity of matches to significantly alter sleep duration was not observed. It should be noted that the effect of exercise on sleep is difficult to measure on elite athletes as they cannot be subjected to much greater exercise intensity as they are already close to maximum (Dolezal et al., 2017). This might explain some of the contrasting findings as most studies were performed on non-elite athletes.

In the literature, short periods of intensified training has been shown to cause significant sleep disruption and mood state disturbances (Killer et al., 2015). It was suggested that intense training pre-dispose athletes to sleep disturbances (Marshall & Turner, 2016). However, these results could not be replicated and no significant relationship between the intensity of exercise and sleep quality could be found in any of the Exercise conditions. It seems that perceived sleep quality is not sensitive enough to be disturbed by the intensity of the exercise in this study. This was supported by a study where no changes in sleep quality could be found after an acute increase in exercise duration during treadmill running at moderate intensity for 90 minutes. Neither actigraphy nor subjective sleep quality ratings were altered (Myllymäki et al., 2012). Also on soccer players, no difference in sleep quality after high-intensity exercise when using self-reported sleep scores or actigraphy measures could be found (Robey et al., 2014). Even after moderate to vigorous exercise intensities were performed shortly before going to bed, no sleep disturbances could be found (Brand et al., 2014). A possible reason for not finding sleep disturbances after vigorous exercise might be attributed to an increase in brain-derived neurotrophic factor (BDNF) after exercise which is believed to enhance sleep. This is in contrast to literature and general consensus reports that evening exercise disturbs sleep quality (Baekeland & Lasky, 1966). Robey et al. (2014) did show sleepiness scores to be significantly higher after training and it is thought that many athletes will report a higher sleep tendency after exercise. This is often mistaken for sleep quality by athletes. The first study on exercise and sleep (Baekeland & Lasky, 1966) found a generally positive relationship between the amount of exercise and deep sleep. Evening exercise tends to increase sleep disturbances due to evening exercise is plausible in exercise acting as a stressor causing a higher central nervous system activation resulting in sleep disturbances.

No significant association between the intensity of training or the intensity of matches with sleep quality were found. This is in contrast with other studies suggesting heavy training sessions to disrupt sleep quality (Juliff et al., 2015). Also, matches have been found to disrupt sleep quality. A significant decline in sleep efficiency of netball players the night after matches compared to training sessions were found and the authors concluded that match intensity seems to reduce sleep quality (O'Donnell et al., 2018). Being elite athletes, it is possible that the intensities the players were subjected to were too low to elicit an appropriate sleep response. Other studies also found that a low-intensity score did not alter sleep quality (Knufinke, Nieuwenhuys, Geurts, Møst, et al., 2018). Again, as was already mentioned, elite athletes might need higher intensities to surpass a threshold where sleep quality is altered, as they are already conditioned to do frequent high-intensity training. Further studies are needed to determine whether the finding of the intensity of training decreasing sleep duration is because of physiological pathways or whether it is influenced indirectly by other mechanisms.

c) Relationship between exercise duration and sleep quality and quantity

It was hypothesised that exposure to longer exercise sessions during training, matches and captain's runs will result in lower sleep quality or shorter sleep duration during the subsequent night's sleep. This hypothesis was accepted. Longer training sessions had a significant negative correlation with sleep duration after training sessions and longer matches had a significant negative correlation with sleep quality on the subsequent night.

This might be an indication that sleep duration is more likely to be affected after training days than sleep quality when training duration is increased. The duration of matches or captain's runs did not have any relationship with sleep duration. A similar finding was made when rugby league players were monitored during a training camp. An increase in training duration was shown to have a trivial negative relationship with total sleep time ($r = –0.04$).

In contrast to the findings of the current study, other studies found an increase in sleep duration with increased training duration (Driver & Taylor, 2000; Youngstedt et al., 1997). Furthermore, it has been shown that low intensity and long duration of exercise resulted in significantly longer sleep duration, but did not alter the depth of sleep or sleep quality (Horne & Staff, 1983). It was suggested that sleep benefits are obtained with aerobic endurance training of more than an hour in athletes

(Chennaoui et al., 2015; Driver & Taylor, 2000). It has been shown that if the exercise duration is of a reasonable length for the general population, one of the health benefits is an increase in sleep duration (Kjeldsen et al., 2012). However, caution should be taken when interpreting these studies as most studies are done at moderate aerobic exercise intensities of moderate duration and participants are usually elderly people or people suffering from insomnia or sleep problems. There is thus much room for improvement in sleep whereas elite athletes might already be getting optimal sleep. This is known as the "ceiling effect". This should be taken into account when reviewing the literature.

At least one study did not show any change in sleep duration after an acute increase in training duration in highly trained individuals (Myllymäki et al., 2012), whereas other studies did show excessive exercise duration (over 2 hours) to elicit a sleep response by increasing sleep duration. This is evident in extreme exercise duration such as in ultramarathons, where large metabolic stress resulted in longer sleep durations. This theory supports the sleep-restoration hypothesis where sleep is an optimal time the body uses to repair itself (Shapiro et al., 1981). Sleep duration was also increased in highly trained cyclists when their training volume was increased by 153% during nine days of intensified training (Killer et al., 2017). However, it was noted that because of the use of a fit population, longer durations of exercise might be required to elicit a significant effect on sleep. The fitness of the athlete is a moderator variable and should be considered when results are interpreted (Nedelec et al., 2018). Elite athletes have the capability of a quicker recovery of the sympathetic nervous system after exercise or the ability to perform greater temperature elevation exercise (Horne & Staff, 1983). Due to the use of elite athletes combined with an average daily duration of training being less than two hours, this might not have been enough to elicit a significant sleep response.

One plausible explanation for the finding in this study of sleep duration having a negative relationship with sleep duration after training might be sleep restrictions resulting from a fixed training schedule. It has been suggested that athletes lose sleep when forced to train at early times in the morning. These early morning training sessions disrupt sleep duration (Fullagar, Skorski, et al., 2015). Athletes cannot go to bed early enough to increase sleep duration before early morning training sessions. This is because of a so-called “forbidden zone” in which it is difficult to fall asleep in the early evenings (Nedelec et al., 2018). Thus, going to bed earlier does not guarantee longer sleep duration. Sleep onset latency might be increased if the tendency to sleep is too low early in the evening (Caia, Scott, Halson, & Kelly, 2017). It is of great importance to note that in studies where sleep duration was increased, sleep was likely administered ad libitum and athletes’ sleep was not restricted by fixed early morning training schedules (Driver & Taylor, 2000). Of three studies reviewed by Youngstedt et al. (1997), two studies produced greatly increased sleep duration after an increase in exercise duration and one study showed a decrease in sleep duration. The two studies where sleep duration increased, sleep was administered ad libitum compared to the study where sleep duration decreased as the participants’ sleep schedule was fixed (Youngstedt et al., 1997).

It has been found in the literature that competition demands may decrease the amount of sleep athletes get (Davenne, 2009). This could not be confirmed as not one of the Exercise Variables showed any significant relationship with sleep duration after match days. However, the average sleep duration was slightly less after matches compared to training and captain's runs. Reasons explaining lower sleep times after competition might be delayed bedtimes due to late-night matches, increased cortisol, sympathetic hyperactivity, elevated core body temperature and muscle pain (Stuart et al., 2019). Other explanations include post-match celebrations and ceremonies while players are also occasionally required to fly back home the morning after the tournament which might cause sleep restrictions and may contribute to a decrease in the average sleep duration after matches.

Given the evidence discussed above, there is evidence of a relationship between sleep duration and training duration. However, it is likely that in this study sleep duration was indirectly affected by training duration, because of fixed training schedules requiring early morning training. In the findings of this study, given that these are all elite athletes, the duration of exercise does not seem to be long enough to elicit a direct physiological effect. There was no certainty in the current study that daily training duration reducing sleep duration directly via physiological pathways, but from the literature, it seems there is a threshold which can be surpassed with the excessive duration of exercise. This will elicit a physiological response as the body needs to recover and this will increase sleep duration. However, future research is required before a conclusion can be made.

Sleep quality showed a significant negative relationship with the duration of matches. This might be an indication of sleep quality being more sensitive to be affected after match days than sleep duration. Other studies support the finding of sleep quality being negatively affected by increased exercise duration, but this was mostly after extreme training durations. Reasons for this were given as muscle soreness and blisters, which again seem to be a more indirect effect of exercise duration on sleep quality, rather than the duration of exercise having a direct physiological effect to disturb sleep quality (Shapiro et al., 1981). It is likely that Rugby Sevens, being a collision sport, injuries and muscle soreness is more prevalent after matches than after other sporting competitions. Match duration does not have to be very long in order for players to obtain significant injuries or to do harm to their bodies. It is also logical that an increase in match duration will expose the player to more muscle damage and a greater probability of injury.

5.5 Research aim two: the relationship between perceived sleep duration and perceived sleep quality

The second aim of the current study was to determine if there is a relationship between sleep duration and sleep quality. It was hypothesised that shorter self-reported sleep duration (quantity) will result in lower perceived sleep quality in Rugby Sevens players during a competitive season. This hypothesis was accepted. The current study showed that sleep quality and quantity are tightly coupled with in a positive relationship.

Sleep duration and sleep quality showed a moderate positive relationship ($r = 0.32$, $p<0.01$). This is very similar to Ehrlenspiel et al. (2018) who found a significant positive association ($r = 0.4$, $p<0.001$) between sleep quality and sleep time in 103 German marathon athletes the night prior to competition. More support for this was provided by Kölling et al. (2016) who found that subjective ratings of sleep, recovery, and stress are negatively impacted by shorter sleep durations whereas an increase in sleep duration reversed these effects. Davenne (2009) made the same conclusion in a review study in which athletes who increased their total sleep times, subjectively reported feeling better when they woke up as well as during the rest of the day.

The mean pSD for all nights in the current study was 469.7 ± 64 min (07:48 ± 01:04 hh:mm) with a sleep quality of 7.8 ± 1.7. This is in range with Knufinke et al. (2018), who monitored 98 elite Dutch youth athletes for a month also using self-reporting and found their sleep duration to be 8:11 ± 0:45 (hh:mm) and sleep quality 6.84 ± 0.92 (1-10 scale). In addition, Knufinke et al. (2018) found a significant correlation between sleep hygiene, sleep quantity and sleep quality. Furthermore, Kirschen et al. (2018) concluded after reviewing 19 studies of elite sports athletes that all studies either show a positive performance outcome with longer sleep duration or the results were neutral.

In the current study it was found that there was a significant reduction in perceived sleep quality reported with every hour of reduced sleep duration. This is of great value as it shows how critical each hour is for sleep quality to the athlete and each hour of sleep is vital to sleep quality. This supports the idea of sleep extensions to be one way of enhancing the benefit of sleep in athletes. Fullagar et al. (2015) found in their review study that sleep extensions are a valuable method off-setting the detrimental effects of sleep loss on physiological and cognitive performance. Numerous other studies also found improved performance after sleep extensions. Collegiate basketball players improved sprint times and shooting accuracy, while mood scores and next day sleepiness were improved (Mah et al., 2011). Sleep extension resulted in moderate improvement in rugby league players' sleep quality scores (Swinbourne et al., 2018). Sleep has been identified to be one of the most effective recovery strategies and an important component of preparation (Donnell et al., 2018). Sleep loss may influence physiological responses to exercise which might hinder muscle recovery or reduce immune function. It might also influence neurocognitive components and mood stability (Fullagar, et al., 2015). It has been hypothesised that people who sleep more and/or better have more energy, a better mood and less sleepiness that would result in an increased propensity to exercise which might again reciprocate to better and more sleep. Contrary to this, less sleep and poor quality might have the opposite outcome leaving the person with less energy (Youngstedt & Kline, 2006). Experimental conditions restricting sleep to less than six hours showed lower daytime activity levels (Kline, 2015). It was suggested that symptoms of the overtraining syndrome might be caused by an imbalance of the autonomic nervous system as a result of a reduction of sleep quality and quantity (Fullagar, et al., 2015). In conclusion (Kirschen et al., 2018) reported after their systematic literature review, competitive athletes will possibly benefit from an increase in sleep duration.

Sleep has been shown to be vital for performance. One night of sleep deprivation decreased task to failure performance and increased RPE during submaximal tasks compared to control conditions in cycling tests (Temesi et al., 2013). Some studies found sleep to be a better predictor of the following day's exercise rather than exercise being a predictor of the subsequent night's sleep (Kline, 2015). Regardless, there seems to be a strong reciprocal relationship between exercise and sleep. This echoes how important sleep quality and sleep duration are for next-day performance.

5.6Research aim three: changes in perceived training load during a 31-week season

The third aim of the current study was to determine if there were changes in training load in the beginning of the season compared to the end of the season. It was hypothesised that professional Rugby Sevens players will report significantly lower perceived training loads at the end of the competitive season compared to the beginning of the season. This hypothesis was rejected, and the alternative hypothesis was accepted.

Even though there were no significant changes ($r = -0.04$, $p > 0.01$) there was a slight decline. Training load showed a cyclical pattern during the 31-week season. Figure 5.1 shows the mean daily training load per week for the team. The blue bars are the training weeks and the yellow bars are the weeks with a tournament. It can be seen that training load increases as the weeks progress closer to the tournaments. Training load usually peaks the week before the tournament and there seems to be a sharp decrease during the weeks of the tournaments. This is followed by an even lower training load the following week as the players are usually given a week to recover. This is also depicted in Figure 5.2. where circles indicate the week before a tournament, the stars indicate the week of a tournament and the triangles indicate the week following a tournament. It can be seen that in the first part of the season, training load following a week with a tournament is low, however, in the second part of the season the training load following the tournament week is absent. This might be part of the periodisation strategy where training loads are decreased following the week after the tournament as the season progressed. This increased recovery time and lowers stress on the players in order to maintain fitness without overreaching. It is important to measure training load longitudinally as the risk of injury and illness can be reduced (Jones, Griffiths and Mellalieu, 2016).

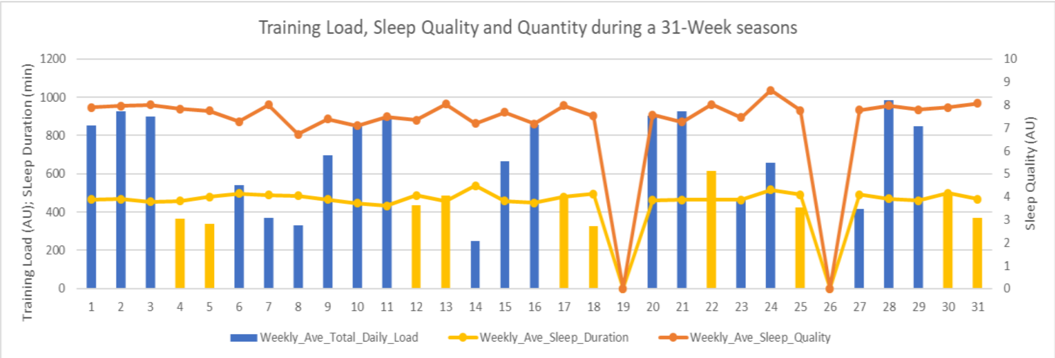


Figure 5.1 *A graph of the mean weekly training load for the team for each week of the season plotted with the corresponding mean perceived sleep quality and quantity for the team. The blue bars represent the training load during training weeks and the yellow bars represent the training load during a tournament week.*

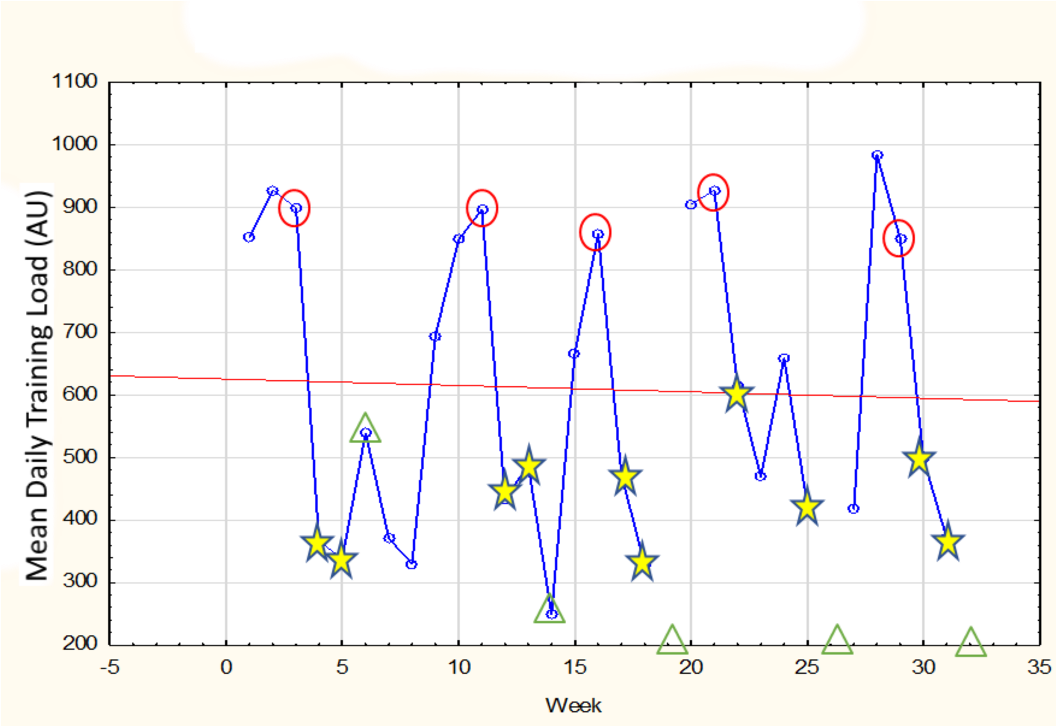


Figure 5.2 *A graph of the mean weekly training load for the team for each week of the season plotted with the corresponding mean perceived sleep quality and quantity for the team. The blue bars represent the training load during training weeks and the yellow bars represent the training load during a tournament week.*

5.7 Research Question four: changes in perceived Sleep Quality and Quantity during a 31-week season

It was hypothesised that professional Rugby Sevens players will report significantly lower sleep quality or quantity at the end of the competitive season compared to the beginning of the season. This hypothesis was rejected and the alternative hypothesis was accepted. No evidence was found in this study of perceived sleep quality or duration to improve or deteriorate during a season. Even though both of these sleep variables increased slightly as the season progressed, it could not be concluded that there was any change in sleep quality or quantity from the beginning of the season compared to the end.

5.8 Conclusion

Table 5.1 This table presents a summary of the research hypotheses stated and the outcomes

Hypothesis	Outcome
a) higher perceived training loads (for training, captain's runs, and matches) will result in lower self-reported sleep quality and quantity.	**Accepted.** Higher perceived training loads did result in lower sleep quality and duration
b) higher perceived exercise intensity (in training, captain's runs, and matches) will result in lower self-reported sleep quality and quantity	**Accepted.** Higher training intensity resulted in lower sleep duration
c) longer exercise duration (in training, captain's runs, and matches) will result in lower sleep quality and quantity.	**Accepted.** Longer exercise duration did resulted in lower sleep duration and quality
d) shorter self-reported sleep duration (quantity) will result in lower perceived sleep quality in Rugby Sevens players during a competitive season.	**Accepted.** A positive correlation between sleep quality and sleep duration was found
e) professional Rugby Sevens players will report significantly lower perceived training loads at the end of the competitive season compared to the beginning of the season.	**Rejected.** No significant difference was found in training loads for the end of the season compared to the beginning.
c) professional Rugby Sevens players will report significantly lower sleep quality or	**Rejected.** No significant difference was found for

quantity at the end of the competitive season compared to the beginning of the season.	sleep quality or sleep quantity in the beginning of the season compared to the end of the season.

To the author's knowledge, this is the first study in rugby sevens to record players' perceived sleep quality and perceived sleep duration over a complete competitive season. This was also a novelty study due to training load and its different components, such as exercise duration and exercise intensity that were individually used to determine which aspect might possibly be responsible for affecting sleep. It was found that there is a relationship between exercise and sleep however, this was only true for certain exercise conditions. Perceived sleep duration and perceived sleep quality seemed to be influenced through a different mechanism as sleep duration only showed a relationship with exercise variables after training days whereas sleep quality only showed a correlation with some exercise variables after match days. Training duration, the intensity of training and the training load of training all showed a negative relationship with sleep duration. The duration of matches and the training load of matches also showed a negative relationship with sleep quality. Further investigation is necessary to determine whether the findings are as a result of a direct or indirect mechanism. It seems likely that the findings can mostly be explained by indirect mechanisms rather than complex physiological processes. A reduction in sleep duration with increase training duration and training load can possibly be explained by early morning training times as more frequent training sessions may result in sleep restrictions. Muscle soreness, injury and sympathetic arousal after matches when match duration and training load increased may be responsible for a reduced sleep quality.

Furthermore, it was shown that there is an association between perceived sleep duration and perceived sleep quality and this study is evidence that perceived sleep duration and perceived sleep quality might be tightly coupled. A longer perceived sleep duration correlated with better-perceived sleep quality irrespective of the exercise condition. This might be the first study to show how vital each hour of sleep is for sleep quality and that for each hour of sleep loss there is a significant decrease in sleep quality. This supports literature on encouraging athletes to enhance sleep duration. This also showed sleep duration to be a vital part of determining sleep quality. Coaches should be aware of the detrimental influences different exercise variables combined with the different exercise conditions have on sleep. A possible solution to improve sleep quality and off-set some of the adverse effects of sleep disturbances during phases of heavy training or tournaments may be implementing sleep extensions by encouraging players to sleep longer or ad libitum and not to a fixed schedule if there is an opportunity in the weekly schedule to do so.

In summary, the main finding of this study was that there is a relationship between exercise and sleep. Sleep duration was decreased after training days. Training duration, training intensity, and training load all had a significant negative correlation with sleep duration. However, sleep quality seems to be altered after matches. Sleep quality negatively correlated with duration and training load of matches. Furthermore, it was found that perceived sleep quality significantly increased with longer sleep duration. The importance of this finding is that players usually have little control over their sleep quality, but do have greater control, to some extent, over their sleep duration. This was further emphasized as sleep quality was significantly higher for every hour sleep duration increased. This shows the importance of each hour of sleep on sleep quality.

Longitudinal analysis showed training load to increase each week before peaking the week prior to a tournament week. Training load was low during tournament weeks with the lowest being the week following a tournament. No change in sleep quality or quantity was observed for the duration of the season.

5.9 Limitations

One of the limitations experienced was the use of only perceived sleep quality and perceived sleep duration assessments. This leaves room for error as it has been shown that subjective sleep scores can be over- or underestimated. The results provided are thus reliant on the accuracy of the players' estimates and the players' honesty in providing feedback. Also, not being able to collect the data in person and to rely on other team members also made room for errors. Unfortunately, this resulted in some data sets not be complete, by either not having training load for the day or no sleep data reported for the night. These data sets could not be included. A more hands-on approach and a robust method of control should be used in the future to make sure data are always captured and not missed. In addition, even though technology is a very helpful tool, players can sometimes hide behind technology as there is no human intervention to keep them accountable for what they report until it is too late and the reported scores have been captured.

Another limitation was the participants being elite athletes and “good sleepers”, which leaves little room for improvement. This is known as the “ceiling effect” where improvements can not easily be achieved due to participants already being at a high level. Being elite athletes, exercise duration, intensities and training load cannot be increased much more as this is also already high.

Furthermore, all confounding variables could not be controlled for and it was acknowledged that there were numerous other influences that may affect the results of this study. Travelling over time-zones, the use of sleep medication and social and family responsibility are some examples of confounding variables on sleep that could not be controlled for, but this is beyond the scope of this study. Attempting to report too much on the co-founding variables (even though necessary) would draw away the focus from the main goal of the study and make it more difficult to read and interpret.

The duration of a training session was recorded for the whole squad which does not necessarily accurately reflect the session duration of an individual player. However, it is important to know that for matches each player’s involvement in the match was recorded individually. This should be taken into account when interpreting the results of the study.

The fact that there were gaps in the data should be taken into account before any conclusions can be made. Furthermore, all data were pooled, not controlling for morning or evening training sessions or matches.

Lastly, although the whole squad was included, this only accumulated to 16 players. Statistical power was reduced, because of this small sample size.

5.10 Future Studies

Future research should look at the difference in subjective versus objective measurements when monitoring the exercise variables. Future studies should also control for other confounding variables such as crossing time-zones and the use of sleep medication. Furthermore, future studies should use a larger sample across multiple sports codes in order to determine if these findings can be extrapolated to other sports.

Another aspect that should be paid attention to in future studies is the sleep quality and quantity on different match days. Due to matches being played on consecutive days, sleep quality and quantity should be investigated after each match day as there might be valuable information in isolating each match day. Also, tournaments are played over two or three days. It will be valuable to measure sleep variables after each day of these days as day one and day two might differ significantly from day three.

5.11 Practical Implications

- Coaches and the coaching staff must be aware that after high training loads sleep quality and sleep duration may be reduced. The necessary precaution must be taken to make sure athletes get the optimal sleep in order to recover.

- An increase in training duration may lead to a decrease in sleep duration. Training sessions must be scheduled appropriately to make sure athletes get the required amount of sleep.

- Sleep quality is reduced after matches and it is advised that the necessary steps are taken to make sure athletes get optimal sleep after matches.

- Better sleep quality was reported with increased sleep duration. Athletes should be encourage to increase their sleep duration during periods of high training volumes.

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Appendix A

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APPROVED WITH STIPULATIONS
REC Humanities New Application Form

10 September 2017

Project number: SPORT-2017-1268

Project title: Sleeping patterns in professional sevens rugby players over a competitive season using cardio enabled wrist watch actigraphy and RPE

Dear Mr Eben Opperman

Your REC Humanities New Application Form submitted on 6 September 2017 was reviewed by the REC: Humanities and approved with stipulations.

Ethics approval period: 11 September 2017 - 10 September 2020

REC STIPULATIONS:

The researcher may proceed with the envisaged research provided that the following stipulations, relevant to the approval of the project are adhered to or addressed.

Some of these stipulations may require your response. Where a response is required, you must respond to the REC within **six (6)** months of the date of this letter. Your approval would expire automatically should your response not be received by the REC within 6 months of the date of this letter. If a response is required, please respond to the stipulations in a separate cover letter titled "**Response to REC stipulations**".

Institutional permission

Permission will be obtained from the South African Rugby Union ethics committee to conduct the study. This was given for the previous version provided ethics clearance had been obtained from the University of Stellenbosch. The stipulation is that the researcher provides the REC with a copy of proof of permission from SARU once this has been obtained.

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your SU project number (SPORT-2017-1268) on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Research Protocol/Proposal	Eben Ethics protocol V13.1docx	27/08/2017	V1
Informed Consent Form	Consent from for athletes	27/08/2017	V1
Data collection tool	Home Osterb 1976(original)	27/08/2017	V1
Data collection tool	psqi_sleep_questionnaire_1_pg	27/08/2017	V1
Data collection tool	2.2. Garmin Vivosmart HR LifeQ	27/08/2017	V1

71%

Appendix B

1 March 2017

To: Simon Opperman
Eben Opperman
Prof. R.E Venter

Your research request was discussed by the SA Rugby Internal Research Review Committee. Please note the following:

1. We support your request to undertake the following research: "Asses the current quality of sleep and sleeping patterns and the effect of training load on the subsequent night's sleep of the SA Men's Sevens Rugby team."

2. SA Rugby requests that you ensure that all ethical and consent requirements are met. Please provide SA Rugby with proof thereof.

3. SA Rugby requests, for its records, a copy of the final research proposal.

4. SA Rugby requests that it is provided with a final draft of the research for internal review.

5. SA Rugby requests that the SA Mens Seven's Rugby team are acknowledged for their support of this project.

6. Please note that SA Rugby does not provide any financial assistance.

Thank you once again for your interest in the game of rugby.

Regards

Dr Jakoet

THE SOUTH AFRICAN RUGBY UNION

Appendix C

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STELLENBOSCH UNIVERSITY

CONSENT TO PARTICIPATE IN RESEARCH

INFORMED CONSENT

Title of Research Project: The relationship of training load on sleep quality and quantity in professional sevens rugby players over a competitive season using cardio enabled wristwatch actigraphy.

You are asked to participate in a research study conducted by **Simon Opperman** (MSc in Sport Science) under the supervision of **Prof R. E. Venter** and co-supervision of **Prof E. Terblanche**, from the **Department of Sport Science** at Stellenbosch University. You were selected as a possible participant in this study because you are a professional sevens rugby player, competing for South Africa as part of the Blitzbokke.

1. AIM OF THE STUDY

The aim of the study is to investigate the relationship between training load and sleep quality and quantity in professional sevens rugby players over a competitive season using cardio-enabled wristwatch actigraphy.

2. PROCEDURES

Wristwatch actigraph

You will be wearing a wristwatch actigraph each night during the competition phase to determine your sleep patterns. The actigraph is a straplike device, the size of a thin watch. You will be asked to download your data from the watch each morning as well as make sure the watch is charge and during the day in order for the watch to function properly for the duration of the sleep.

Horn Ostberg self-assessment questionnaire

This questionnaire will show if you are more inclined to performing at your best during the morning or later the afternoon. You will complete a paper hard copy of the questionnaire once during the competitive season.

Training Load

Your Training Load will be determined by multiplying your Rate of Perceived Exertion (RPE) by the duration of the exercise in minutes. The RPE is a subjective score that will be collected by your trainer after each training session. You will be asked to give your perceived intensity of the session on a scale from 1 – 10, where 1 is “effortless” and 10 is “extremely hard”.

3. POTENTIAL RISKS AND DISCOMFORTS

There will be no serious risks involved in the study. All the assessments and procedures are non-invasive. Wearing the wristwatch actigraph should not be uncomfortable due to the fact that it is small, light, and resembles a small watch.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will receive full feedback at the end of the study. This study should help you to identify possible sleep disturbances you might experience due to travel, competitions and training and could help you to have improved sleep quality and quantity. Feedback will be given to the coach and support staff in terms of general patterns of the players to enable them to intervene if necessary and manage jet lag effectively.

5. PAYMENT FOR PARTICIPATION

As a participant you will not receive any financial reimbursement or payment to participate in the study.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of withholding the names of the participants and only using numerical codes to represent subjects. This means that reported results will only include codes and no names at all. Recorded data will be filed and stored on a cloud-based server, that is only accessible through an API using an outh-token for security. Only the researcher and promoter have access to the API. All information obtained in the study will not be disclosed, unless published, in which case it will be treated as not to identify anyone.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to take part in this study or not. If you volunteer to participate in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Participation will be discontinued if you fail to comply with the testing protocol. Your consent to participate in this research will be indicated by your signing and dating of the consent form.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact the researcher Simon Opperman (0768541783 or simono@sarugby.co.za) or the supervisor, Prof. R. E. Venter (021 808 4915 or rev@sun.ac.za).

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me by Simon Opperman (researcher) in Afrikaans and English and I am in command of one of the languages. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of the project information form.

____

Name of Subject/Participant

____

____

Signature of Subject/Participant **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to __________________________

and he was encouraged and given ample time to ask me any questions. This conversation was conducted in Afrikaans and English and no translator was used.

____ ______________

Signature of Investigator (Simon Opperman) **Date**

Appendix D

A self-assessment questionnaire (Horne & Ostberg)

Instructions:

*Please answer all the questions truthfully.
*Please circle or mark the block with the most preferable answer to you.

Questions:

1. Considering only your own "feeling best" rhythms, at what time would you get up if you were entirely free to plan your day?

[AM:][Noon

5:00	5:30	6:00	6:30	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00

2. Considering only your own "feeling best" rhythms, at what time would you go to bed if you were entirely free to plan your evening?

[PM:][AM:]

8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00

3. If there is a specific time at which you have to get up in the morning, to what extent are you dependent on being woken up an alarm clock?

Very dependent	Fairly dependent	Slightly dependent	Not at all dependent

4. Assuming adequate environmental condition, how easy do you find getting up in the mornings?

Very easy	Fairly easy	Not very easy	Not at all easy

5. How alert do you feel during the first half hour after having woken in the mornings?

Very easy	Fairly easy	Not very easy	Not at all easy

6. How is your appetite during the first half-hour after having woken in the mornings?

Very good	Fairly good	Fairly poor	Very poor

7. After the first half-hour after having woken in the morning, how tired do you feel?

Very refreshed	Fairly refreshed	Fairly tired	Very tired

8. When you have no commitments the next day, at what time do you go to bed compared to you usual bedtime?

More than 2 hours later	1 – 2 hours later	Less than 1 hour later	Seldom or never later

9. You have decided to engage in some physical exercise. A friend suggests that you do this one hour twice a week and the best time for him is between 7 – 8 AM. Bearing in mind nothing else but your own "feeling best" rhythm, how do you think you would perform?

Would be on good form	Would be in reasonable form	Would find it difficult	Would find it very difficult

10. At what time in the evening do you feel tired and as a result in need of sleep?

[PM:][AM:

8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30	3:00

11. You wish to be at your peak performance for a test that you know is going to be mentally exhausting and lasting for two hours. You are entirely free to plan your day and considering only your own "feeling best" rhythm, which ONE of the four testing times would you choose?

8:00 – 10:00 AM	11:00 AM – 1:00 PM	3:00 – 5:00 PM	7:00 – 9:00 PM

12. If you went to bed at 11:00 PM, at which level of tiredness would you be?

Not at all tired	A little tired	Fairly tired	Very tired

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following events are you most likely to experience?

Will wake up at usual time and will NOT fall asleep	Will wake up at usual time and will doze thereafter	Will wake up at usual time , but will fall asleep again	Will Not wake up until later than usual

14. One night you have to remain awake between 4:00 – 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the following alternatives will suite you best?

Will NOT go to bed until watch is over	Would take a nap before and sleep after	Would take a good sleep before and nap after	Would take ALL sleep before watch

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own "feeling best" rhythm, which one of the following times would you choose?

8:00 – 10:00 AM	11:00 AM – 1:00 PM	3:00 – 5:00 PM	7:00 – 9:00 PM

16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 – 11:00 PM. Bearing in mind nothing else but your own "feeling best" rhythm how well do you think you would perform?

Would be on good form	Would be on reasonable form	Would find it difficult	Would find it very difficult

17. Suppose that you can choose your own work hours. Assume that you worked a FIVE hour day (including breaks) and that your job was interesting and paid by results. Which FIVE CONSECUTIVE HOURS would you select?

Midnight Noon Midnight

12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

18. At what time of day do you think that you reach your "feeling best" peak?

Midnight												Noon												Midnight
12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12

19. One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?

Definitely a "morning" type	Rather more a "morning" than a "evening" types	Rather more an "evening" than a "morning" type	Definitely an "evening" type

Appendix E

Sleep Assessment Questionnaire

Instructions:

The following questions relate to your sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

During the past month,

1. When have you usually gone to bed? ____________________
2. How long in (minutes) has it taken you to fall asleep each night? ____________________
3. What time have you usually gotten up in the morning? ____________________
4. A. How many hours of sleep did you get at night? ____________________
   B. How many hours were you in bed? ____________________

5. During the past month, how often have you had trouble sleeping because you:	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
A. Cannot get to sleep within 30 minutes				
B. Wake up in the middle of the the night or early morning				
C. Have to get up to use the bathroom				
D. Cannot breath comfortably				
E. Cough or snore loudly				
F. Feel too cold				
G. Feel to hot				
H. Have had dreams				
I. Have pain				
J. Other reason (s) please describe, including how often you have had trouble sleeping because of this reason (s):				
6. During the past month, how often have you taken medicine (prescribed or "over the counter")to help you sleep?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?				
9. During the past month, how would you rate your sleep quality overall?	Very good	Fairly good	Fairly bad	Very bad